metallurgia and metal treatment

Vol. 28 : No. 192 SEPTEMBER, 1961 Price 2/6

Heat treatment

Write to:
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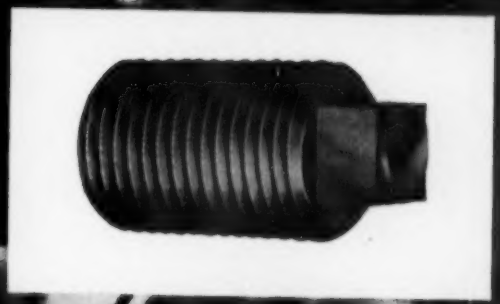
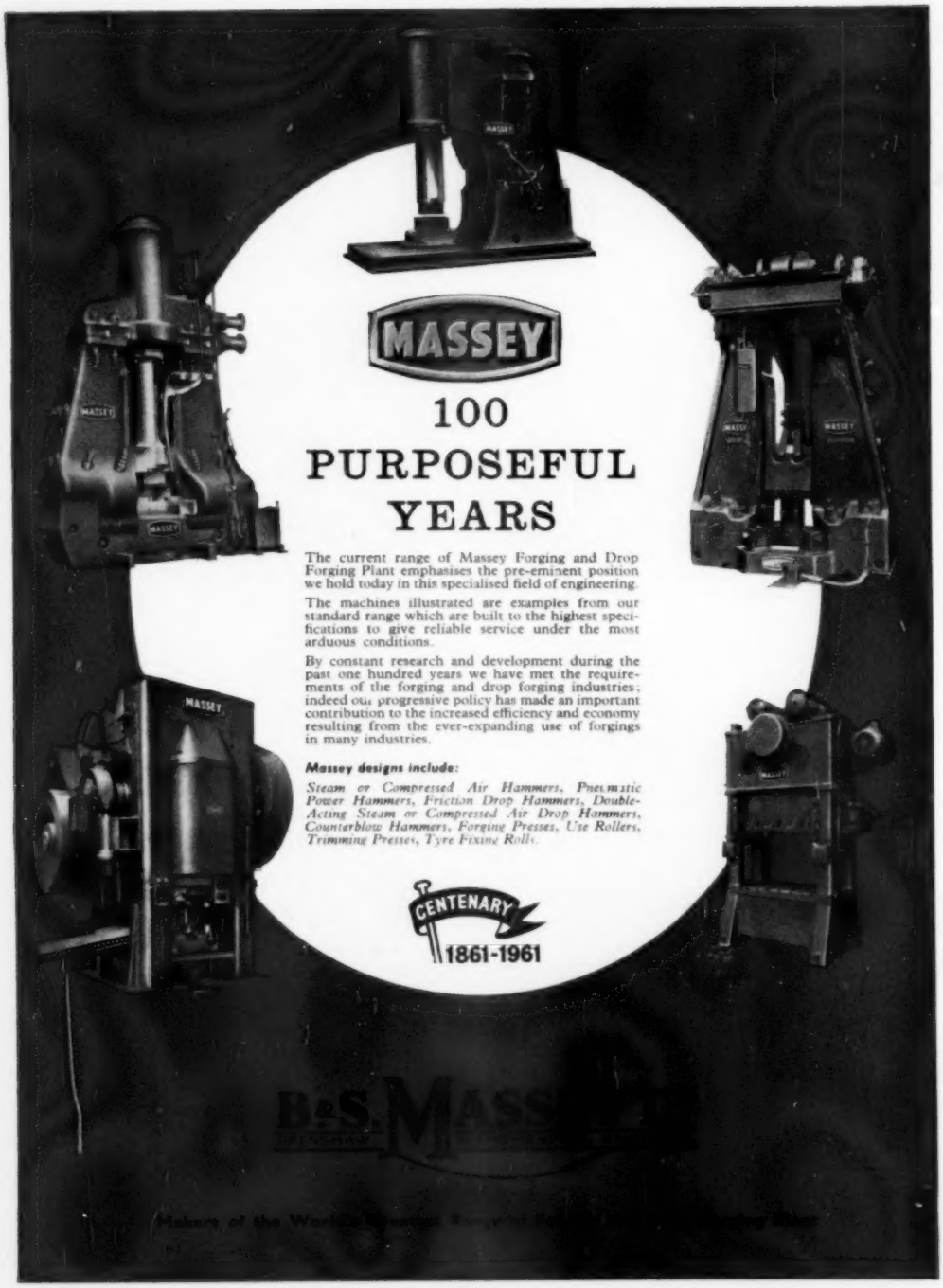
London, S.W.1.

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The current range of Massey Forging and Drop Forging Plant emphasises the pre-eminent position we hold today in this specialised field of engineering.
The machines illustrated are examples from our standard range which are built to the highest specifications to give reliable service under the most arduous conditions.
By constant research and development during the past one hundred years we have met the requirements of the forging and drop forging industries; indeed our progressive policy has made an important contribution to the increased efficiency and economy resulting from the ever-expanding use of forgings in many industries.
Massey designs include:
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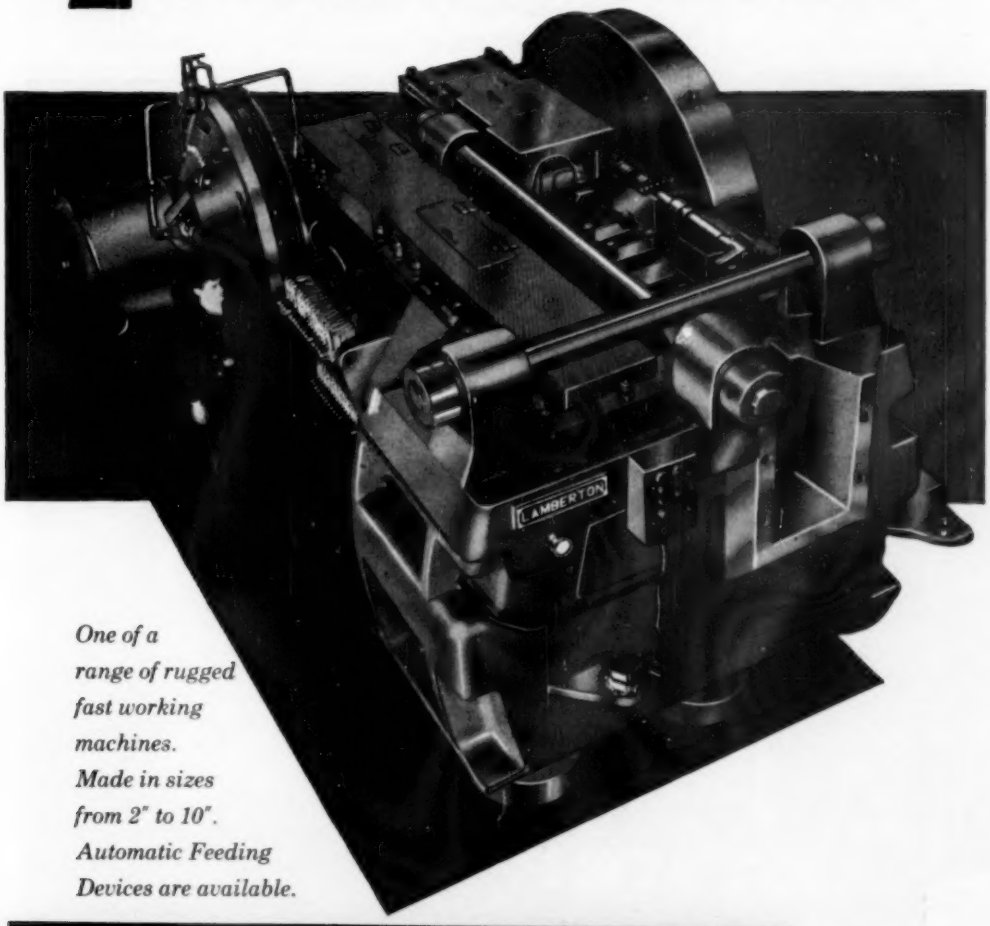

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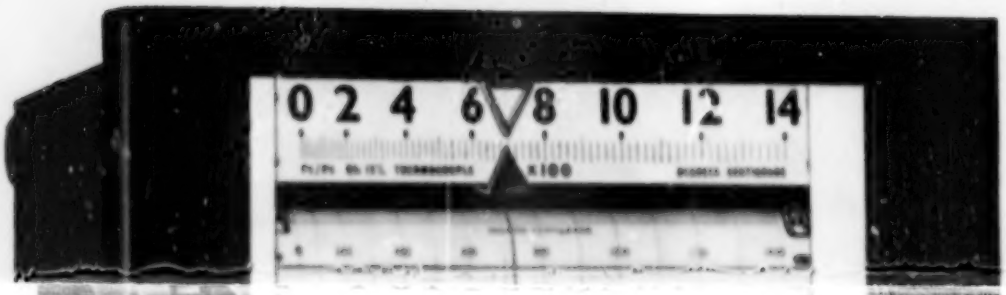

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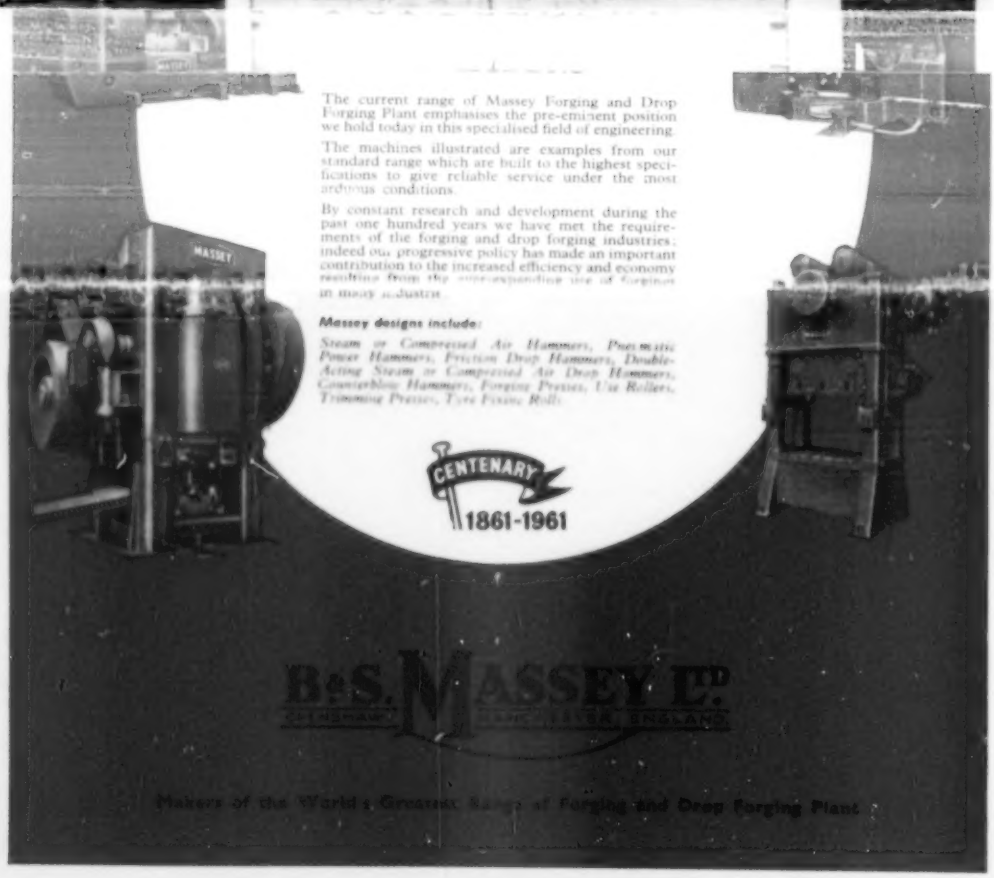

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6" calibrated scale * Standard ranges: 2mV-100mV span
Pen speed: 1, 2 or 4 secs. across chart * Chart life: 1 month at 1 inch per hour.

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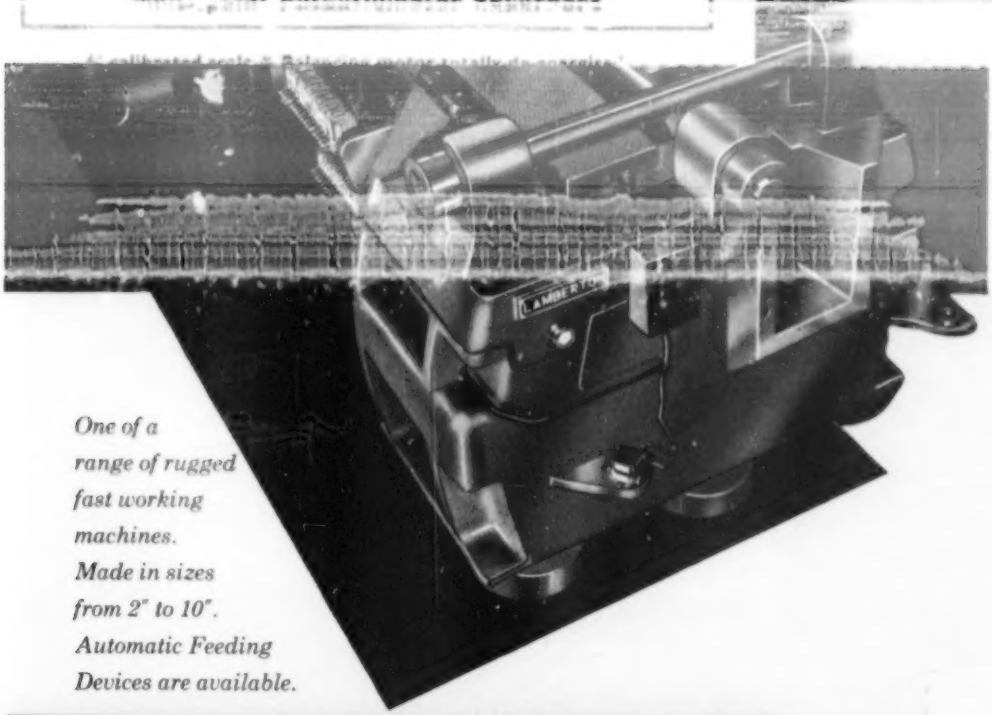

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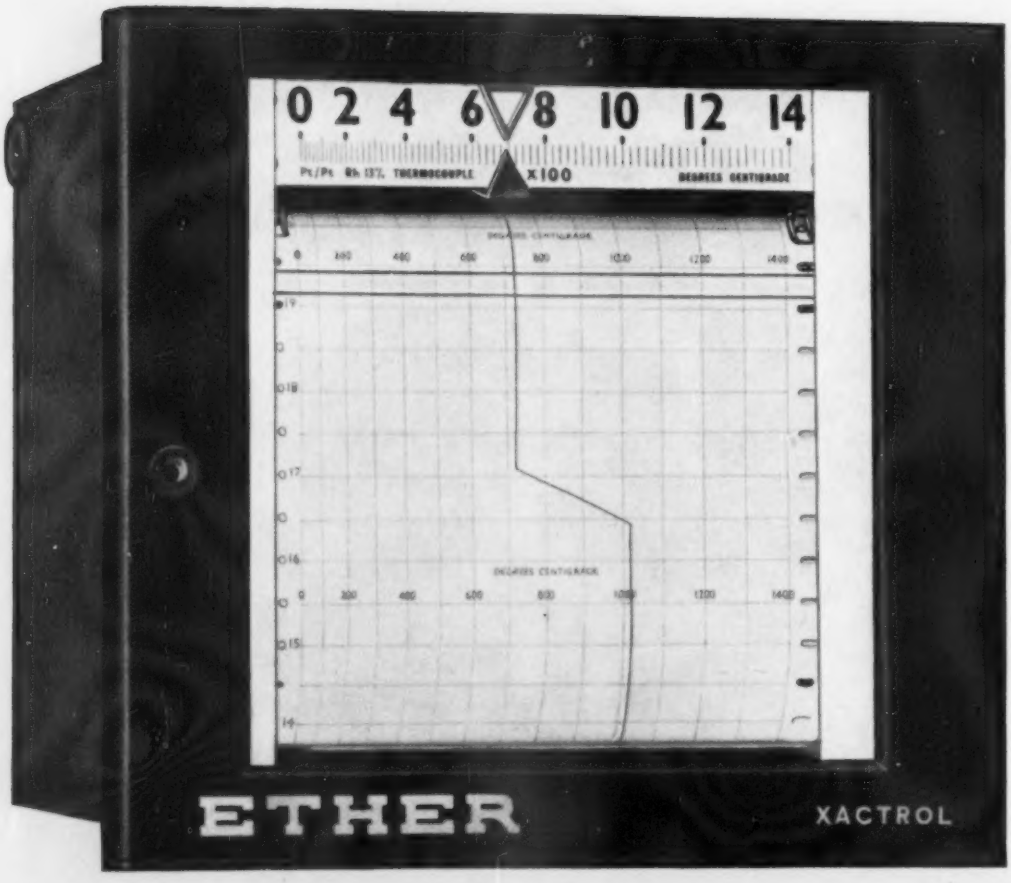

–for indicating, recording and

TEMPERATURE · SPEED · FLOW · PRESSURE · STRAIN · RESISTANCE · CONDUCTIVITY · pH

POTENTIOMETERS

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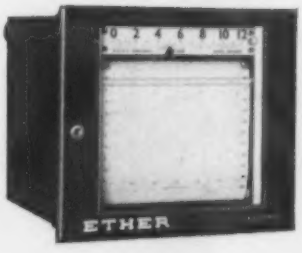

6" calibrated scale * Balancing motor totally de-energised throughout printing and indexing cycles *
Standard ranges: 5mV-100mV span *
Pen speed: 2 secs. across chart * Printing speed: 6 secs. per point

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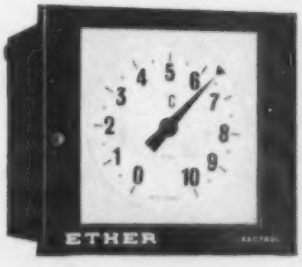
SERIES 2500
Single-point Potentiometer Indicating Controllers



18" calibrated scale * Standard ranges: 5mV-100mV span * Response speed: 2 secs. across chart * Bold easy-to-read scale and pointer.

Available with (i) Two-position on/off control (ii) Anticipatory control (iii) Proportioning (electrical) control (iv) Three-position control (v) Programme control (vi) Proportioning (motorised) control

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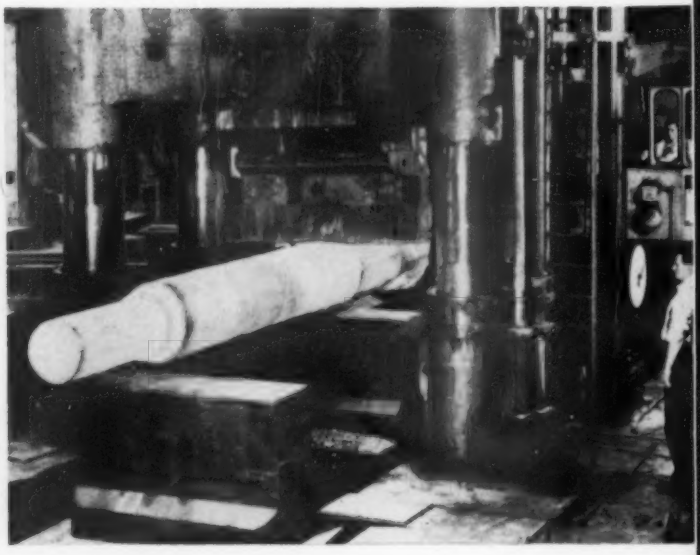

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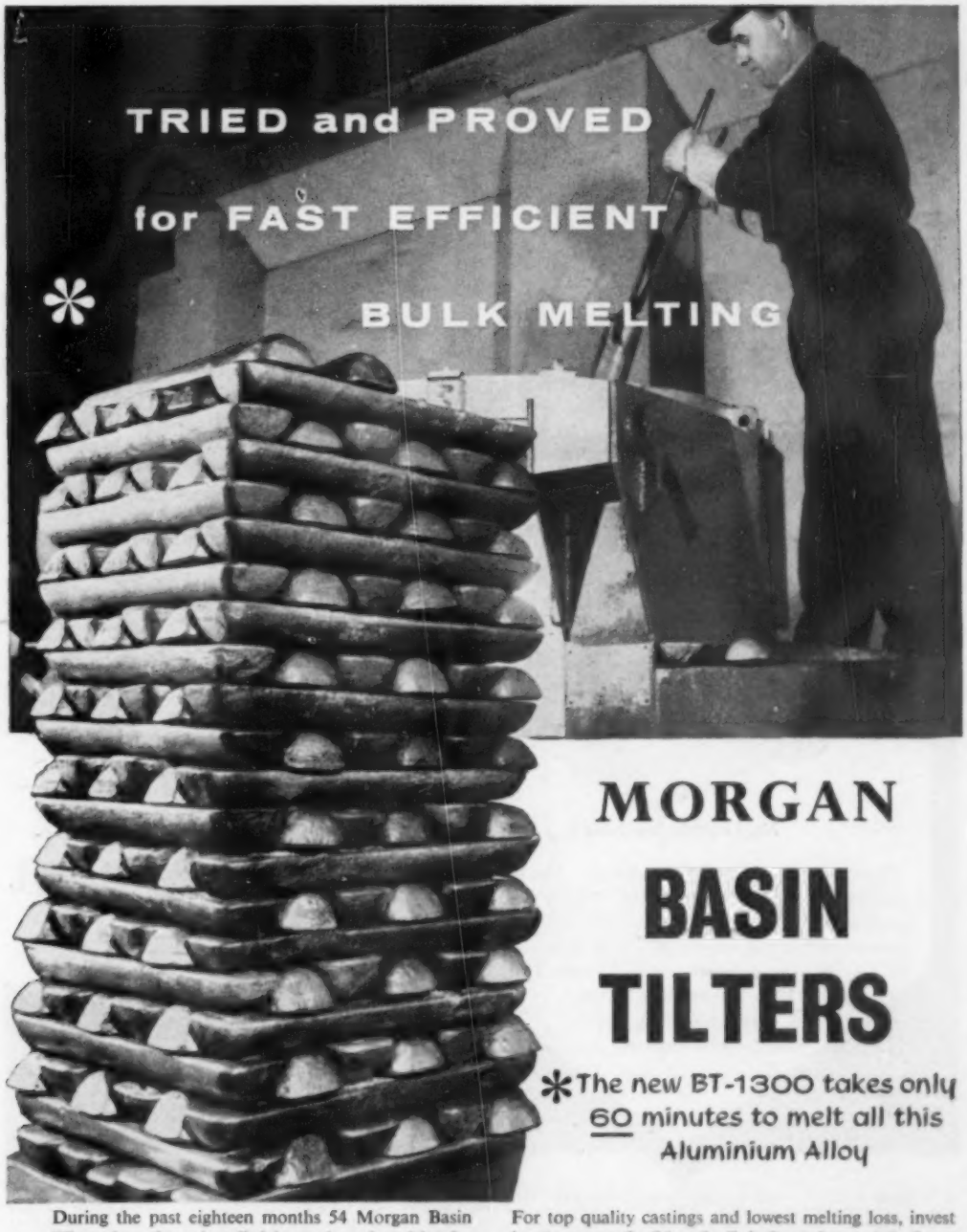

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*The new BT-1300 takes only 60 minutes to melt all this Aluminium Alloy

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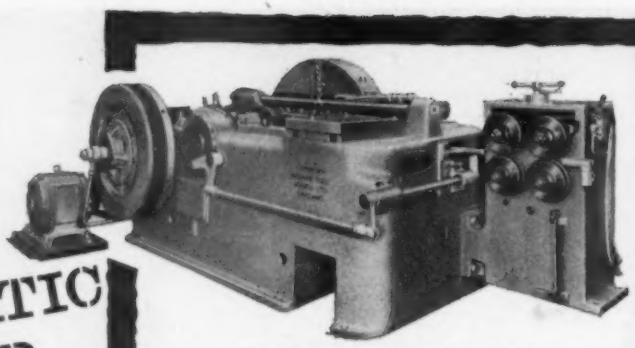
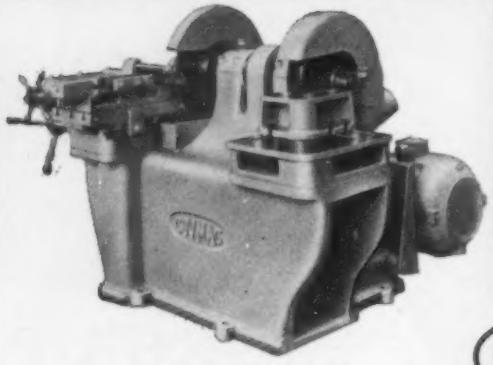
AUTOMATIC FORGER



No. 2 machine with guards removed

The stock is placed between the rolls and is then fed through the dies to the workstop. The die then closes, cutting off the stock to the required length, and delivers it to the heading position. The heading tool then completes the forging, which falls down the chute and is taken away by conveyor.

The Automatic Forger can be supplied in several sizes and for making balls of up to and including 4-in. diameter.



No. 3 machine illustrated

These machines are made in three sizes. The smallest handles bars up to 2-in. diameter. The largest size, as illustrated, takes bars up to 4-in. diameter. They are an invaluable asset to any forging or drop stamping plant.

We also make nine sizes of Standard Upsetting Machines to take bars from ½-in. to 6-in. diameter

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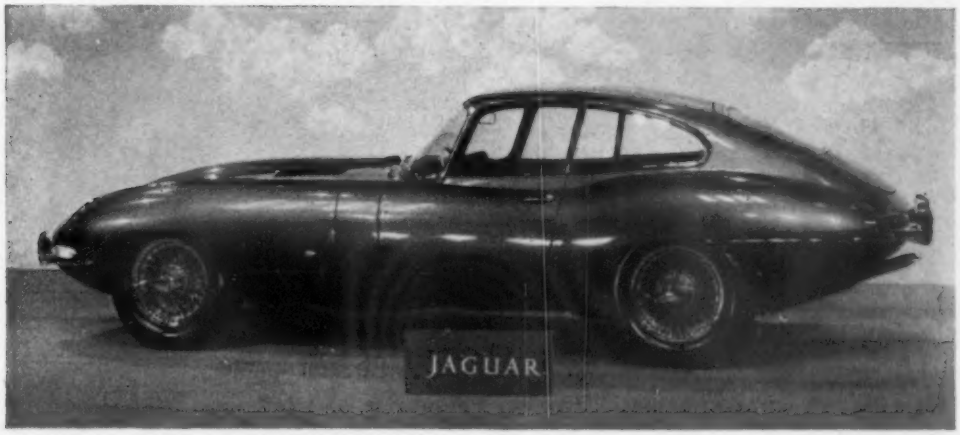

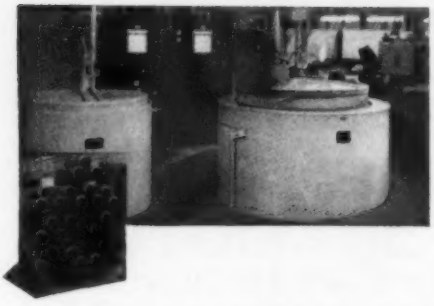

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Jaguar Model E

combines the superb performance of a racing car with the comfort and reliability of a family saloon.

HOMOCARB ELECTRIC GAS CARBURISING

WE are indebted to the Jaguar Company for the above photographs of the new Model E and part of their Homocarb furnace installation. Homocarb with its twin advantages of forced circulation and exact temperature/time control has won world-wide recognition as will be seen from the following list of some important users.

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Send now for descriptive literature or a Technical Representative will visit you at your convenience

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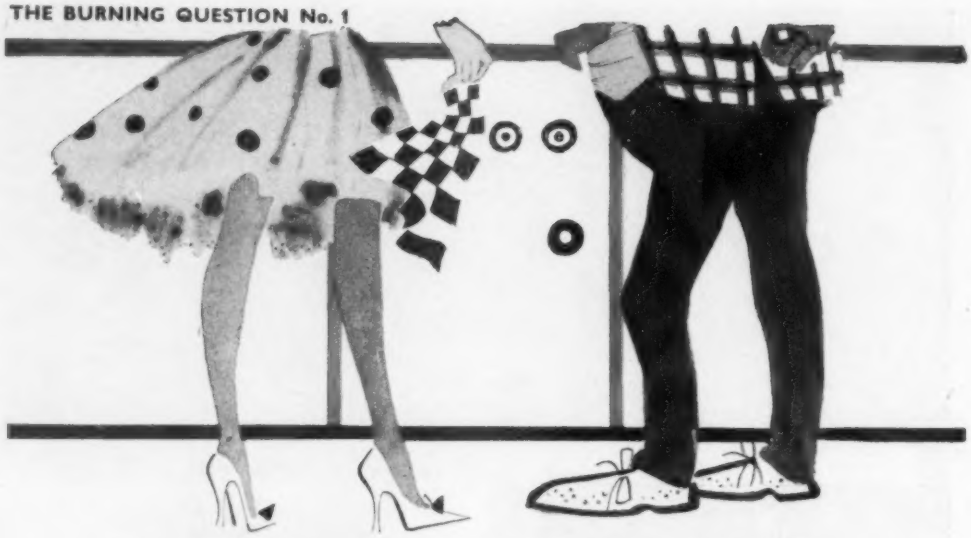
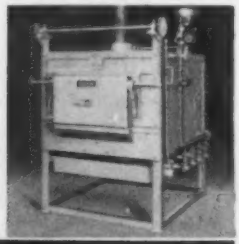
THE BURNING QUESTION No. 1



"WHAT'S COOKING" IN THIS OVEN ?

A special type of carbon steel.
SHOULD BE NICELY BAKED WHEN IT COMES OUT!
'Case hardened' is the term.
REMINDS ME OF SOMEONE I KNOW!
Which, as I was about to say, means that its exterior is being hardened for various engineering operations.
This Brayshaw oven furnace will heat to a temperature of 1200°C.
THAT REMINDS ME—HOW DO YOU WANT YOUR STEAK?
MEDIUM RARE OR CASE HARDENED?



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GENERAL HEAT TREATMENT, PROCESS HEATING, TESTING, FORGING, METAL MELTING, GALVANISING, TINNING. You name it, Brayshaw will supply the complete answer. Write today for full details of the entire range of BRAYSHAW furnaces, Gas, Oil or Electric—for ALL industrial heat treatments.

'HYNOR' OVEN FURNACE

For operating temperatures of 650/1200°C. Extensively used for hardening of carbon steels, normalising, annealing, pre-heating, case-hardening and general heat treatment.

Brayshaw burns to serve your industry

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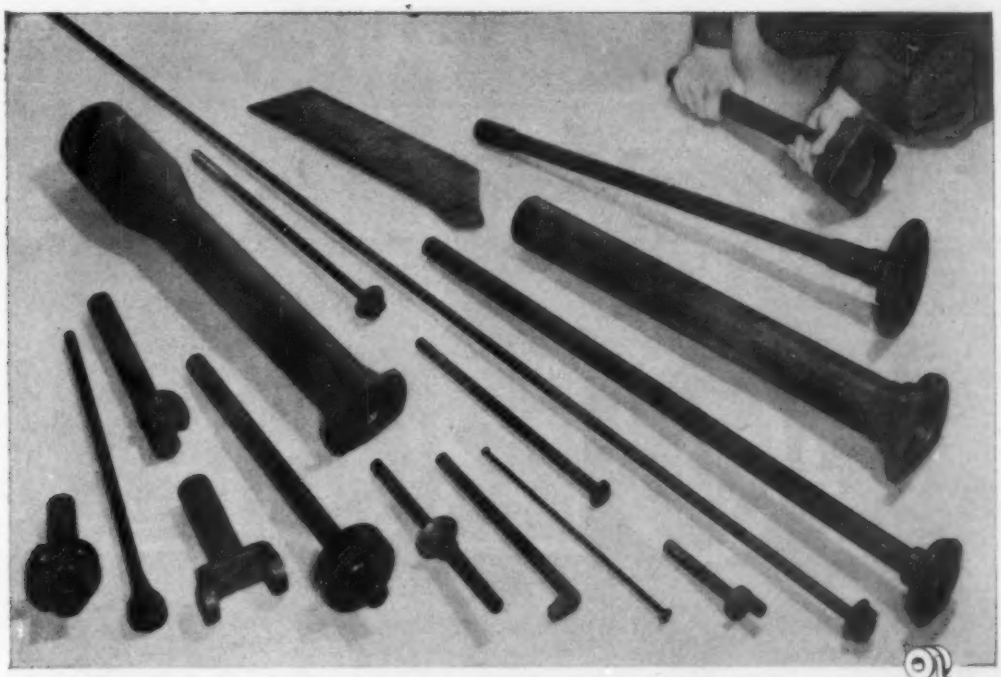

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Let National Tong-Feed Forging Machines Produce *Your* Forgings at Lower Cost

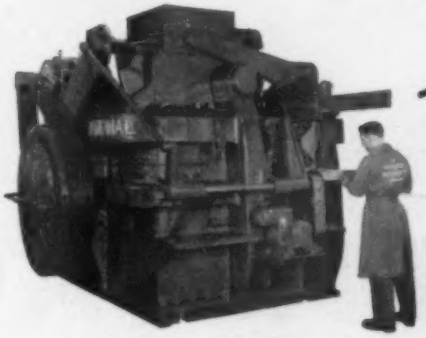
Hot Forging is going automatic!

Well, not *all* of it, but many forward-looking forge plants are taking a fresh look.

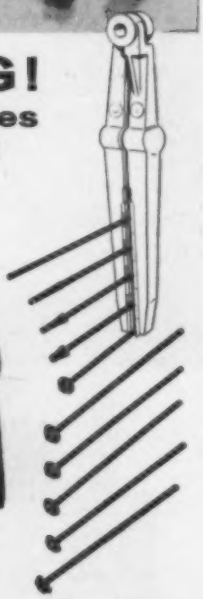
For example, all of the upset-type forgings above were made on National Automatic Tong-Feed Forging Machines. Seven sizes are now proved and presently operating in production: 1", 1½", 2", 3", 4", 6" and 7½".

The method offers extremely interesting opportunities of raising production while reducing labor and operating costs. May we help you investigate?

Let's start by looking over your jobs, in your plant, in Tiffin or in Nürnberg. We can have a productive session devoted entirely to your plans, but without obligation.



National 4" Automatic Tong-Feed Forging Machine with discharge conveyor.



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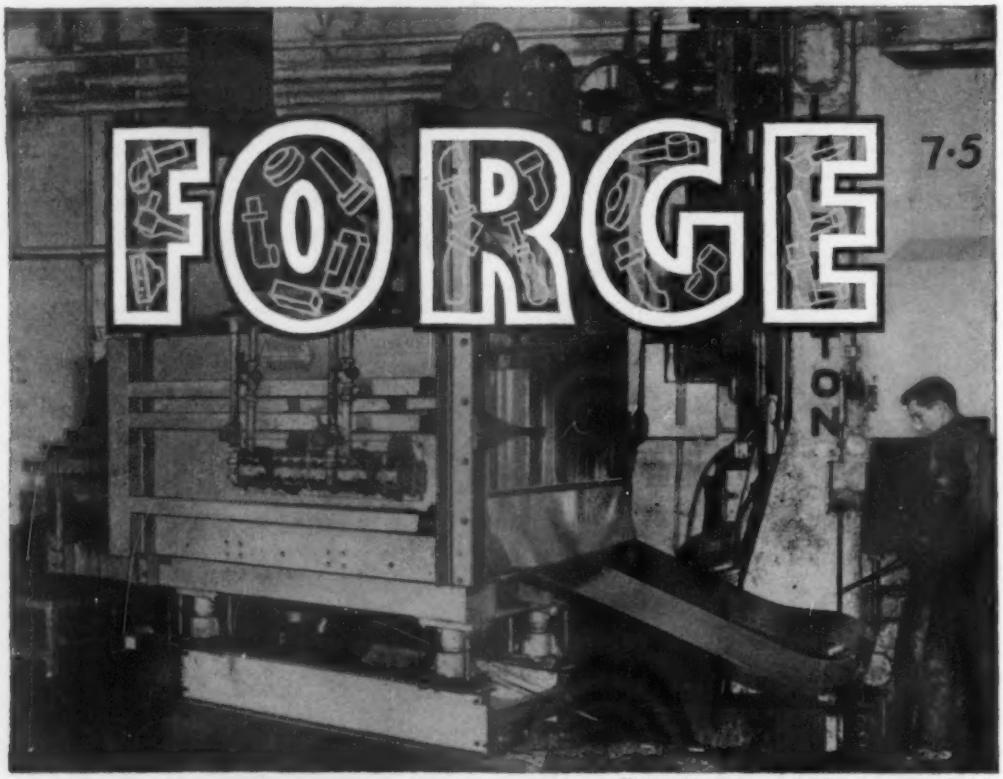

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A wide range of standard or tailor-made mechanised forge furnaces is available, Pusher Type - Rotary Hearth Type - Conveyorised Bar End Heating, with GGC scale-free heating system or fired by gas or oil. The photograph above illustrates a small Thermic Magazine Feed Pusher furnace fired by CC Burners. Output: 7-cwts. of small billets per hour.

Thermic Equipment & Engineering Co. Ltd.

(Subsidiary Company of Gibbons Bros. Limited, Dudley)

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HEAVY PIPE FLANGES UP TO THE LARGEST AND OTHER DROP FORGINGS in 1 HEAT & 3 BLOWS ON ONE PRESS!

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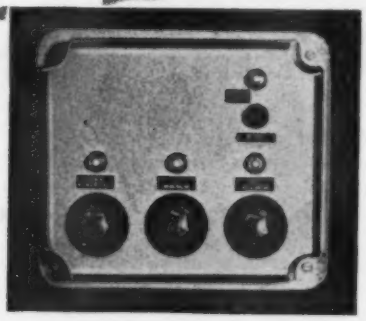
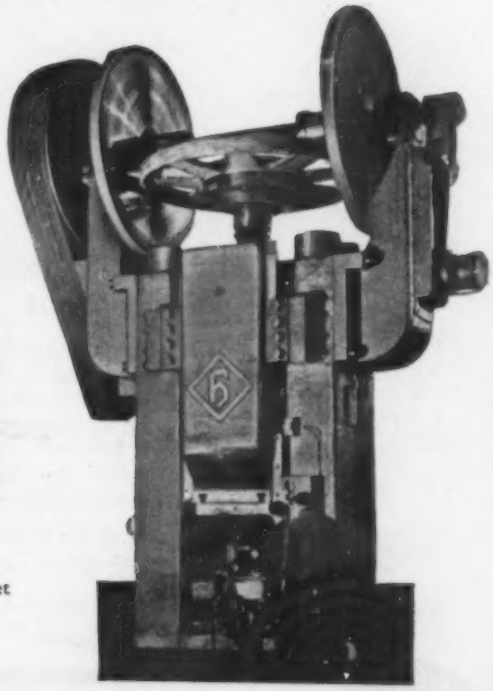
NEW Electronic Control





A unique feature of these presses enables cycle, blow and programme to be preset accurately. Push button operated models from 150 to 3,000 tons are available for hot or cold forging or coining.

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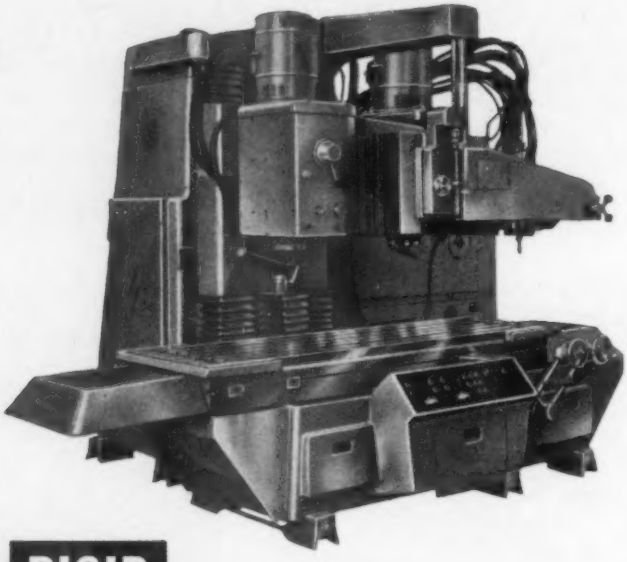
Copies Left- and Right-hand die halves simultaneously



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Fully automatic — roughing and finishing — this exceedingly robust bed-type machine copies 3-dimensional dies, without supervision, from wooden or plaster models. Both left- and right-hand halves of the die can be copied at the same time from the same master. 360° profiling can be performed at constant feed, without rotating circular tables, *and* on vertical contours. Servo hand control permits speedy roughing. The machine has two spindles; single- and 4-spindle machines are available also.

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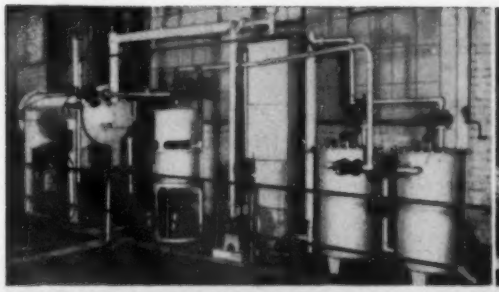

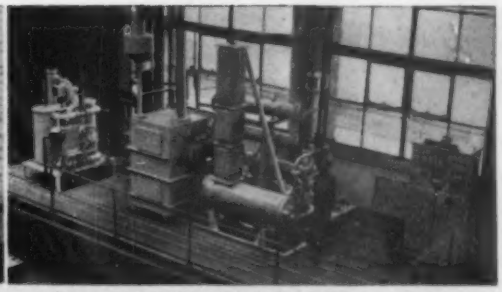

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Metalectric bright annealing furnaces have all the latest features, designed for reliable operation—accurate temperature control, removable sections for easy inspection and maintenance, exceptional fuel economy. All these are backed by the facility for using the best form of atmosphere for the product. Town gas, propane and butane, kerosene or ammonia may be used as the fuel source for the atmosphere.

Top left: A conventional exothermic plant, with primary and reactivated secondary drying units and equipment for removal of sulphur compounds.

Top right: A fully automatic plant for producing commercially pure nitrogen with extremely low dewpoint.

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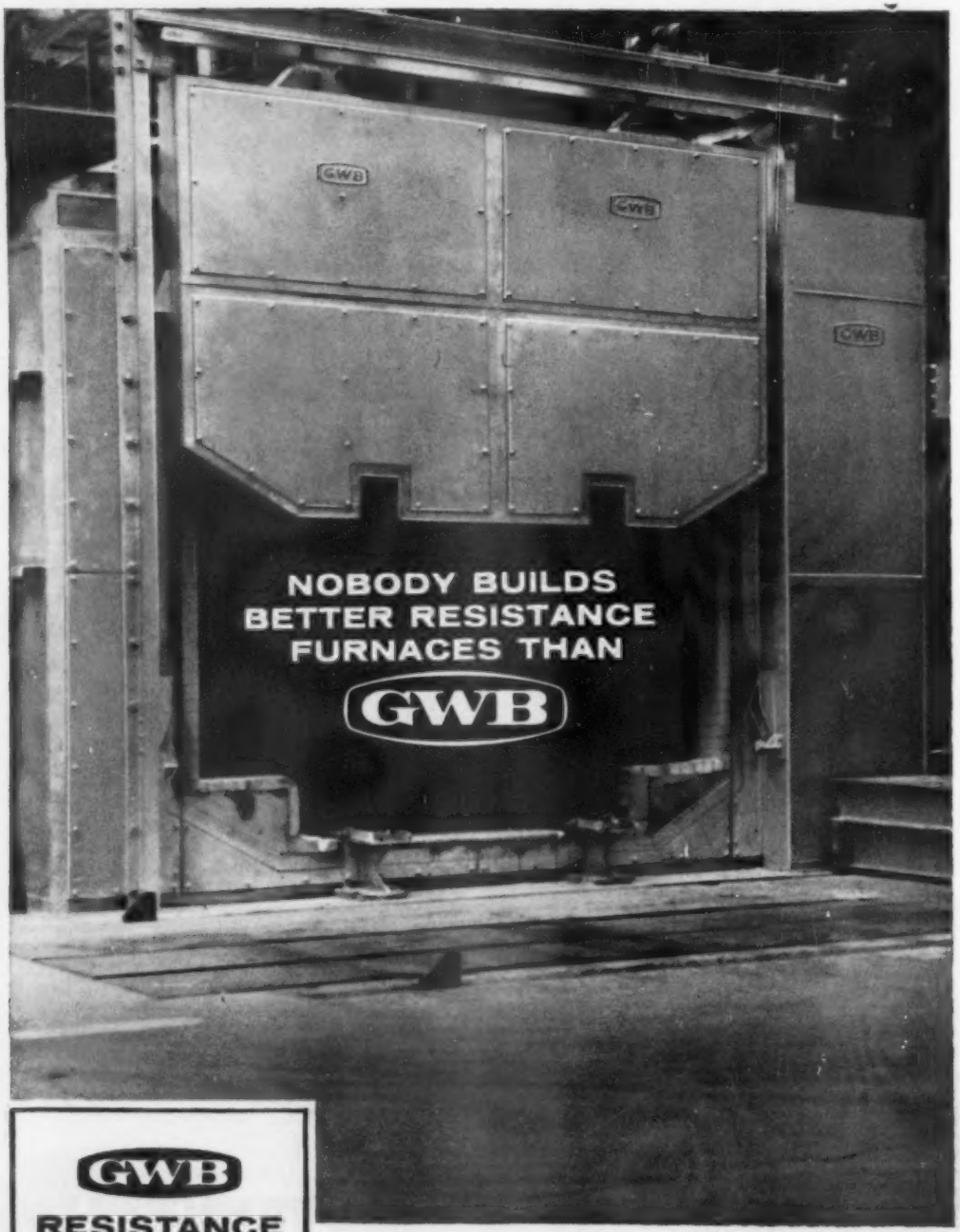

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Very high refractoriness

Complete volume stability

Resistance to Thermal shock

Very high strength

Excellent load bearing properties

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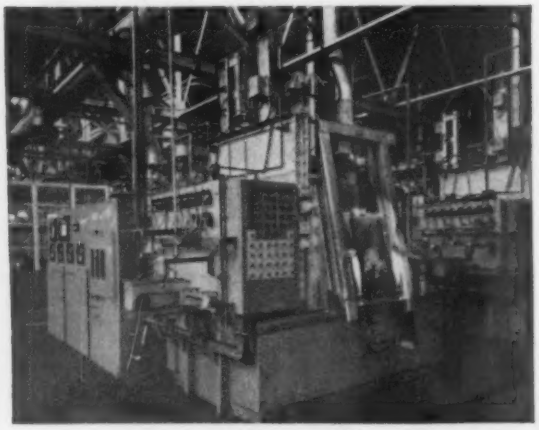

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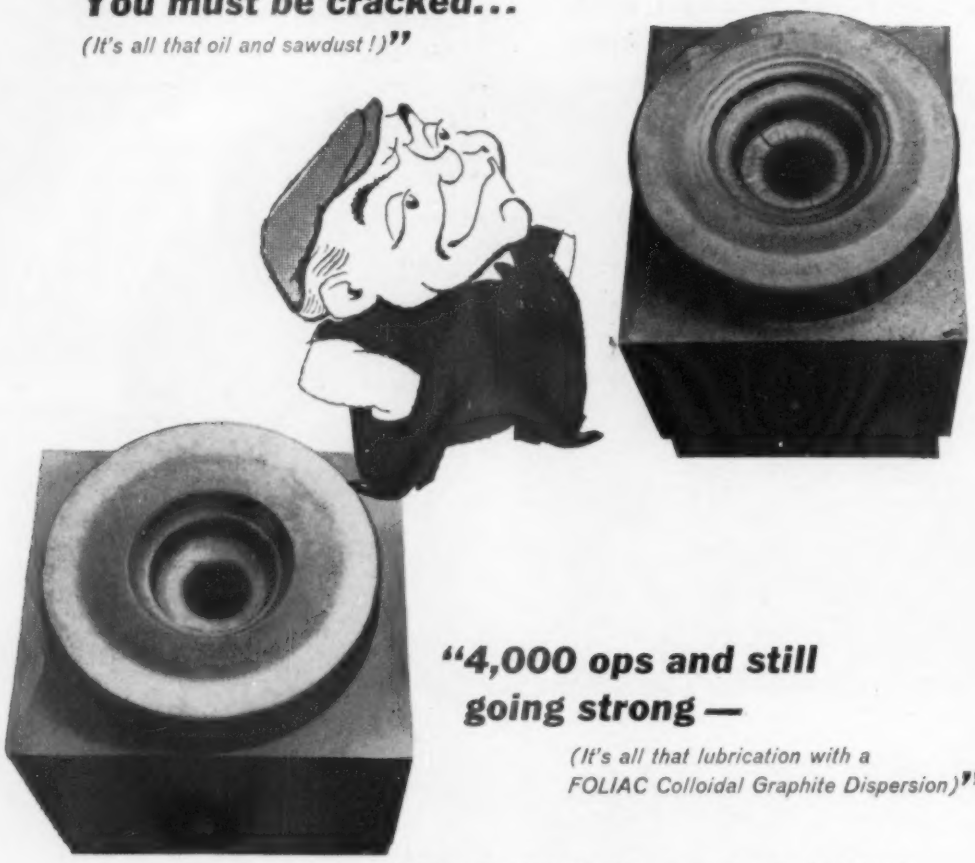

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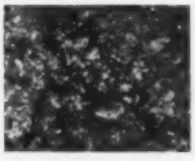

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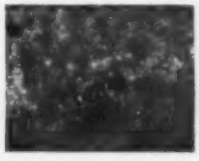

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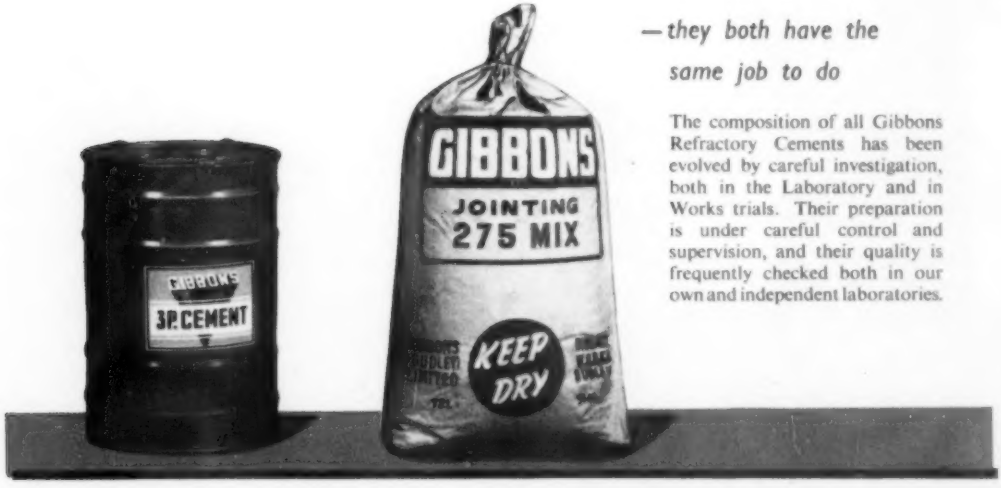

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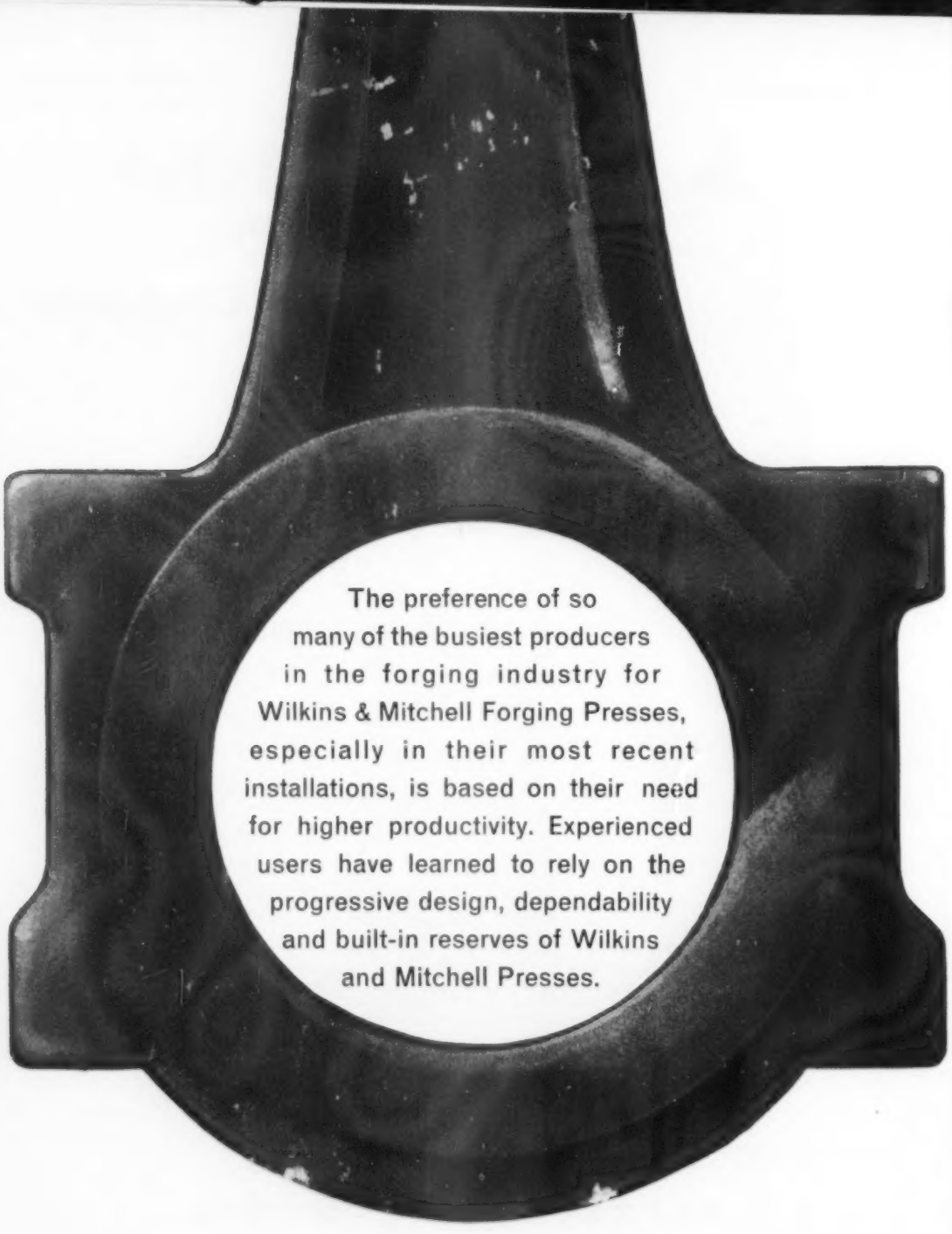

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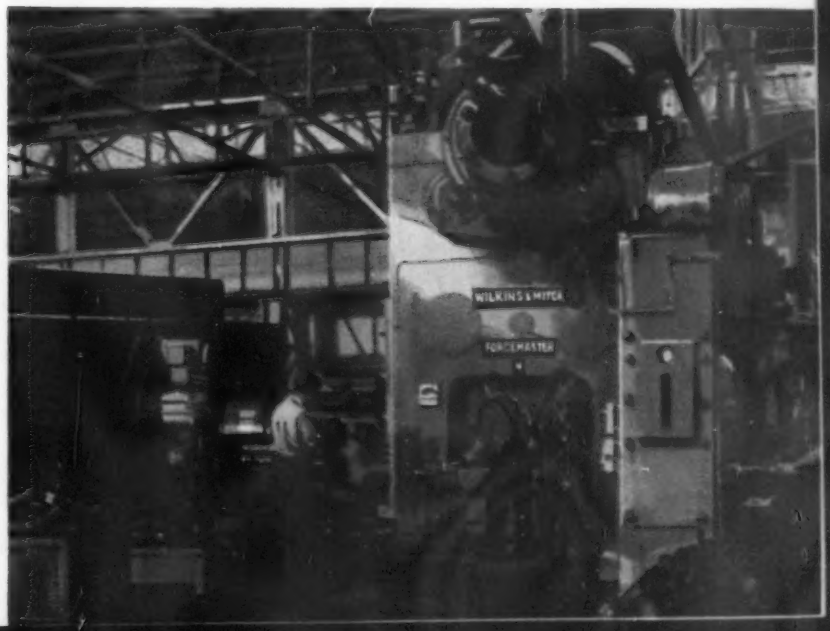

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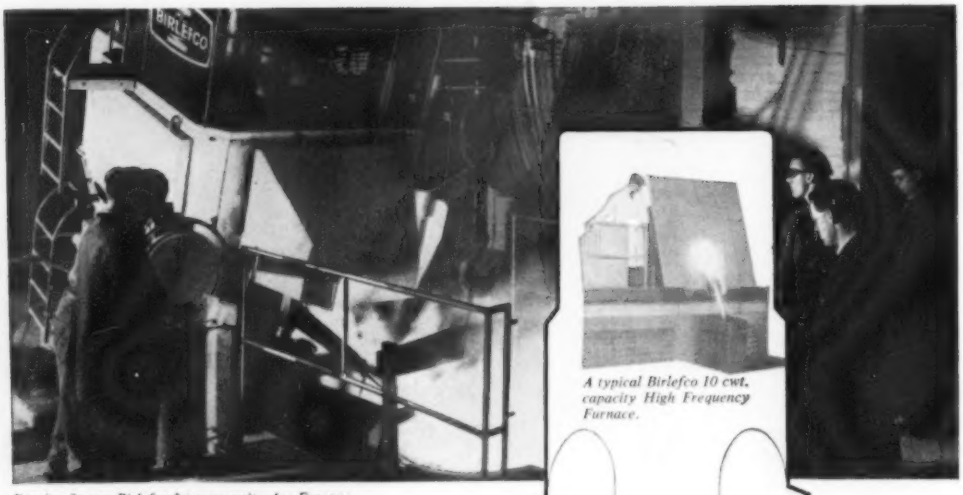

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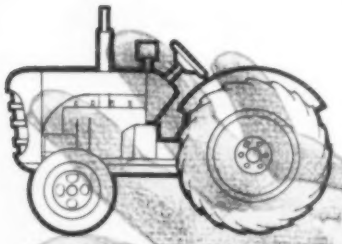

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W.B. 101

Research in the steel industry

LAST year saw a greatly increased expansion and modernization of the British steel industry. Capital expenditure for the year was at the record level of £145 million, as against £95 million for 1959, and is expected to rise to about £200 million this year. It is obvious that these vast increases would not be undertaken unless they were seen to be vital to the competitive position of the industry in world markets, and it is encouraging to see that the steelmakers are alive to the necessity for development. What is not quite so encouraging, however, is still to find insufficient recognition that tomorrow's development depends on today's research. As an example of the results of failure in the past to give due recognition to this dependence, we may take the present balance of steelmaking processes in this country, and the trends envisaged for the immediate future.

According to the British Iron and Steel Federation's publication, ' Steel in the 1960's ' . . . ' Production from the open-hearth furnaces will still predominate and the tonnage will increase; and this is very much bound up with the intensive application of oxygen to open-hearth furnaces. The open-hearth proportion, however, is expected to decline from 84% in 1960 to 68% in 1965 on the basis of capacity available, but in terms of output might be still less. It might be thought that when a works requires substantial new additional steelmaking capacity this is likely to take the form of one of the new pneumatic processes or of electric-arc furnaces. It is unwise to be dogmatic, however, because oxygen use is still in the process of rapid development and the use, *e.g.* of a combined oxygen/fuel lance, might improve still further the competitive position of the open-hearth process, with its valuable flexibility in the proportions of hot metal and scrap used.'

The underlying uncertainty of this cautious approach is a good example of the inevitable results of insufficient development work on the newer steelmaking methods. Had pilot plant trials of the new Continental processes been seriously undertaken in this country from the start, we would now have valuable knowledge and experience to call upon when planning for future development. It is significant that the BISF article gives no indication of the comparative costs or qualities of steels produced by the different processes.

Research in the iron and steel industry is largely in the hands of the industry itself. In addition to supporting the work of the British Iron and Steel Research Association and other research associations connected less directly with the industry to the extent of about £1 million a year, various steel companies have their own research departments, bringing the total research expenditure to something over £5 million a year. Direct Government grants to the relevant research associations amounted in 1960 to less than £200,000—a not very princely sum, but one which compares not unfavourably with those of other major industries.

How large a proportion of net output do major industries consider it reasonable and necessary to spend in research? Different industries would have different answers. According to 1960 DSIR report, in 1958, the proportion for electrical engineering was 10%; chemicals, 6%; iron and steel, less than 1%. These figures are not put forward as a criticism of the iron and steel industry. Obviously conditions will not be the same in different industries, although only figures relating to comparable-sized industries are given. The figures do suggest, however, that there may well be a case for seeing whether any important aspect of iron and steel research is handicapped for lack of funds. The industry is in an expansive mood. It should be a good moment for the claims of research to be considered afresh. A sum, only a fraction of that contemplated for development, spent on research now might prove an equally worthwhile investment.

Scale adherence on steels

A critical review of recent work

R. ROLLS,* M.Sc., A.I.M., A.M.Inst.F.

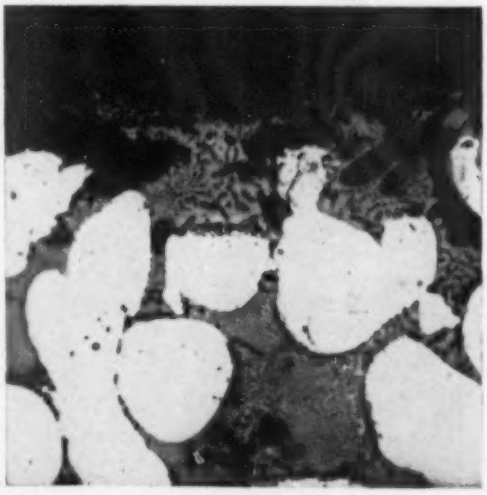
Adherent scales on steels are considered to be a great disadvantage to the maintenance of surface quality during hot-working processes; they lead to excessive tool wear, high machining costs and economically unattractive descaling or pickling operations. Previous work on this problem is reviewed, and it is concluded that the use of higher reheating temperatures to produce a thick scale rapidly, thereby minimizing the concentration of residuals at the metal/scale interface, and the maintenance of an optimum oxidation potential during reheating, contributes to the formation of non-adherent scales. For a 0·3% C steel, reheated in a combusted producer-gas atmosphere (containing 0·1–0·15% SO_2) with approximately 35–45% excess air, soaking at 1,250°C. for 4 h. gave rise to a non-adherent scale

ADHERENT SCALE forming on steel during reheating for hot-working has long been a practical problem concerning fuel technologists and metallurgists alike. The disadvantages of attempting to work steel with a clinging scale are only too familiar in the form of poor surface quality products, excessive tool and die wear and high machining costs; lengthy descaling or pickling operations may be economically unattractive. It is generally accepted that the nature of a reheating furnace atmosphere can largely govern the manner of scaling of a steel. But opinions differ as to what factors can be readily controlled to provide minimum metal loss, for a specified reheating schedule, with a conveniently detachable scale prior to hot-working.

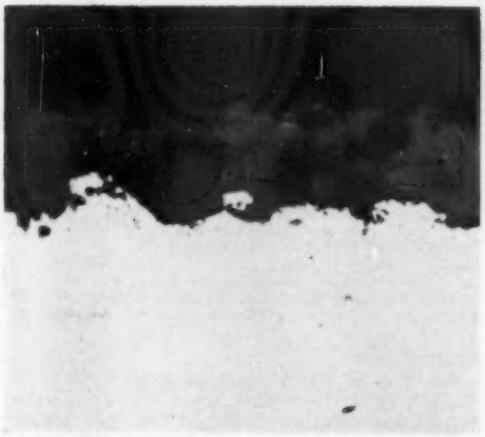
Previous work

Since the fundamental work of Cobb, [1, 2] Murphy,[3, 4] Preece[5–8] and their colleagues, which clearly showed the significance of free oxygen and sulphurous gases in promoting adherent scales, others[9–15] have examined the mechanism of sulphur penetration through a scaled steel surface and established the existence of mixed zones of oxide/sulphide complexes (fig. 1) and high residual concentrations of copper, tin and nickel in the sub-surface regions. In atmospheres containing free oxygen, scaling may occur rapidly and the rate of removal of iron is often greater than the rate of diffusion and concentration of residuals. The resultant interfacial enrichment is then insufficient to promote

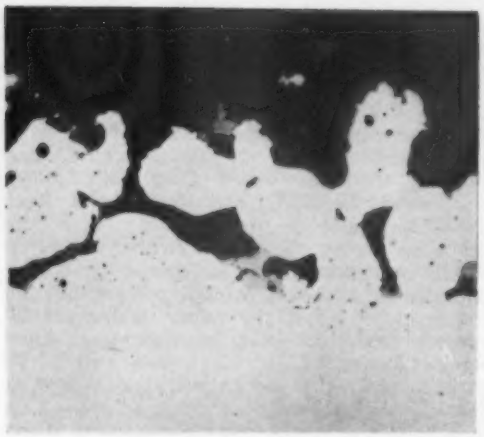
1 *FeO/FeS eutectic at the metal/scale interface of a 0·05% C steel scaled for 1 h. at 1,150°C. in a mixture of FeO and FeS. Unetched.* × 500



* The author, formerly with Rotherham College of Technology, has recently joined the staff of the Department of Chemical Engineering, Fuel Technology and Metallurgy, the Manchester College of Science and Technology.



2 *The metal/scale interface of a 0·18% C steel reheated for 1 h. in the range 1,200°-1,250°C. in an oxidizing furnace atmosphere. Rapid scaling has given rise to a non-adherent scale. Unetched.* × 500



3 *The metal/scale interface of a 0·05% C steel scaled for 1 h. at 1,150°C. in a 'neutral' atmosphere (80% N_2, 10% CO_2, 10% H_2O) containing 4% free oxygen, showing the adherent nature of the scale. Unetched.* × 500

a hot-short condition in the metal, though it may affect the plasticity and adherence of the adjacent scale (*cf.* figs. 2 and 3).

Edström,[16] investigating 18/8 stainless steels scaled at 1,050°C. in oil-fired reheating furnaces, found that in atmospheres containing free oxygen a transition took place from an adherent to a flaky oxide, associated with a chemical breakdown of an early formed, slowly growing oxide film with a high chromium content. He showed that sulphur in the furnace atmosphere increased scaling rate and produced an adherent scale when excess CO was present, but otherwise did not markedly alter the behaviour when free oxygen was present in the atmosphere.

With plain carbon steels, Engell and Peters[17, 18] studied the interrelationships between scale formation, adhesion and oxidation kinetics. They concluded that adhesion decreased with increased rolling temperature in the case of unkilled steels, killed steels showing no such clear relationship; that adhesion decreased with increased scale thickness (also found by Sachs and Pitt[21]); that formation of intermediate layers containing silicate, between steel and wüstite, was important for scale adhesion on killed steels and that wüstite began to dissociate on slowly cooling scale below 570°C., but did not affect scale adhesion. Further work using pure iron with additions of specific elements showed that, for elements whose oxides have a higher free energy of formation than for iron, their oxides react with wüstite (*e.g.* Al, Si, P) forming intermediate layers between wüstite and metal, reducing the adhesion; for elements whose oxides are soluble in wüstite, *e.g.* Mn, they only noticeably reduce adhesion; and for elements with a considerably smaller free energy of formation of oxide than iron, they precipitate between wüstite and metal. This was found to be particularly so for Cu and S which precipitates as FeS. The plasticity of these precipitates induces stresses between scale and metal, thus increasing the adhesion.

The relationship between the constitution of scales formed on mild steels and their ease of removal by pickling or mechanical descaling has been investigated.[19, 20] It was suggested[20] that where a seam of magnetite (Fe_3O_4) occurred at the metal/scale interface then the scale may be expected to be more adherent. Scale was found to spall off more easily under stresses due to cooling or handling when the seam was absent. Recently reported work by Sachs and Pitt,[21] describing the removal of scale from steel rod by stretching, showed that the total amount of scale and weight of adherent scale increased with time and temperature of oxidation, while the proportion of adherent scale was independent of these factors but tended to increase with carbon content; the weight of adherent scale and its proportion of the total decreased as the scale grew thicker.

Tylecote,[22] reviewing the information concerning the adherence of oxide films on metals, emphasized the possible effects of volume ratio, surface configuration, film plasticity, the diffusion mechanism and the relative expansion coefficients of metal and oxide. In the absence of plasticity, it was considered that adherence at high temperatures was

primarily due to a balance between inward and outward diffusion of metal and oxygen. In non-plastic films differential contraction on cooling could result in the spalling of otherwise adherent films. Using relatively pure iron, Tylecote's investigations[23] indicated that there should be a marked difference in the adherence on cooling between specimens cooled from an oxidation temperature of 900°C. and those cooled from 1,000°C. The phase change from α to γ iron upon heating in the neighbourhood of 900°C. results in a contraction and an increase in the coefficient in the γ-range. This contraction is of the order of 1% of the volume and might be expected to markedly affect the adherence of scales formed above 910°C. Given some degree of plasticity and a slow cooling rate, scales formed at 1,000°C. might therefore be more adherent than those formed at 900°C., provided they were of the same thickness.

Some factors affecting scale adhesion

The following table represents a simplified analysis of some of the factors which have been shown to influence scale adherence:—

TABLE 1

Material	Favouring adhesion	Minimizing adhesion
Pure iron	Cu and S precipitated between wüstite and metal at the interface	Intermediate Al, Si, P oxides reacting with wüstite at the interface
		Presence of oxides soluble in wüstite (*e.g.* MnO)
Plain carbon steels	Free oxygen and sulphurous gases in the furnace atmosphere	Increased rolling temperature (for unkilled steels)
	A magnetite seam at the interface	Increased scale thickness
	Increasing carbon content	
18/8 Stainless steel	Sulphurous gases with excess CO in the furnace atmosphere	Free oxygen in the furnace atmosphere leads to a transition to flaky oxides

The author has obtained results[24] for a killed 0·3% C steel, soaked at temperatures in the range 600°–1,250°C. for periods up to 4 h. in synthetic atmospheres containing 80% N_2, 10% CO_2, 10% H_2O, 0·1% SO_2, with 0, 2, 5 and 7% free oxygen respectively (simulating up to 45% excess air in a combusted producer-gas atmosphere), which, as shown in table 2, compare favourably with the above indications.

TABLE 2

% composition	Favouring adhesion	Minimizing adhesion
C— 0·31 Mn— 0·64 Si— 0·24 S— 0·050 P— 0·027 Ni— 0·15	Scaling at 1,100°C. with up to 7% free oxygen in the furnace atmosphere	Scaling at 1,250°C. with 5–7% free oxygen in the furnace atmosphere
Cr— 0·08 Mo—Tr Cu— 0·25 Sn— 0·064	Scaling at 1,250°C. in a neutral atmosphere† containing 0·1–0·15% SO_2	

†80% N_2, 10% CO_2, 10% H_2O; assuming complete combustion of a typical producer gas.

Conclusions

Where it is impracticable to avoid scaling, the controllable factors which appear to *minimize* the formation of adherent scales are:

1. The production of a thick scale, by using higher reheating temperatures and/or working at an elevated temperature.
2. The prevention of residuals concentrating at the metal/scale interface, by rapid scaling.
3. The maintenance of an oxidation potential to promote the formation of a greater proportion of wüstite (FeO) than magnetite (Fe_3O_4) at the metal/scale interface.
4. For a 0·3% C steel, reheated in a combusted producer-gas atmosphere (containing 0·1–0·15% SO_2) with approximately 35–45% excess air, soaking at 1,250°C. for 4 h. gave rise to a non-adherent scale.

Acknowledgments

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Mechanical working by the vibration method

M. YA KARNOV and A. A. VORONIN

Although vibrations are usually undesirable in machine operation, some vibrations have been shown to benefit certain forging operations. This Russian investigation has been translated from 'Kuznechno-Shtampovochnoe Proizvodstvo,' No. 3, 1960

VIBRATIONS OCCURRING during the operation of various machines represent harmful phenomena. But, as a result of a whole series of tests and observations in practice, it has been established that, during the mechanical working of metal, vibrations of a definite frequency and amplitude are extremely beneficial and, in many instances, lead to a speeding up of the technical processes.

The present work gives the results of an investigation of the process of vibration forging to determine its technical characteristics and obtain certain parameters for the development of the relevant technical forging processes.

In fig. 1 is shown the kinematic diagram of a vibration press installed in the forge shop of one of our Russian works.

The vertical ram of the press 3, which is mechanically connected with the vibrator 2, sets up vibrations in the vertical direction. The stroke and frequency of the vibrations of the ram 3 are dependent on the setting of the mechanical vibrator and can be varied within relatively wide limits.

The static force, P_{st} from the hydraulic system of the press ensures the closing together of the parts of the die between which the billet is located.

By carrying out vertical vibrations, the ram 3 strikes against the top half of the die, setting up an additional pulsating load during forging.

Experimental details

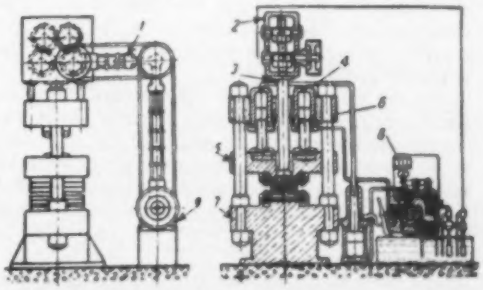
Investigations were carried out at one of the works and under laboratory conditions.* As equipment for the experiment, use was made of an experimental vibration press having the following characteristics:

Maximum static force, P_{st}, from the hydraulic pressure	100 tons
Maximum value of the variable force, P	350 tons
Maximum frequency of the vibrations of the ram of the vibrator ..	1,500/min.
Range of vibrations of the ram of the vibrator, A	From < 1 –25 mm.

For comparison, part of the experiments were carried out on a stamping press with a maximum working force of 1,000 tons. Specimens were prepared from 40KhNMA steel and AK-6 and VD-17 aluminium alloys. For the basic experiments use was made of cylindrical specimens, with the direction of the fibres along the axis of the specimens, 25 mm. in diameter and 10 and 20 mm. high. The specimens were turned to No. 6 finish, and the end faces were ground to No. 7. The height dimensions of the specimens were maintained with an accuracy of $\pm 0{\cdot}02$ mm.

The specimens were compressed in the cold and hot states with and without lubricant. During the compression of specimens under the various working conditions (*i.e.* static, vibrational, static and vibrational), observations were made of the plasticity hardness, macro- and micro-structure and mechanical properties of the metal being worked. At the same time the operation of the vibration press was studied and checked.

For recording the operating forces and the



1 *Kinematic system of the vibration press*
1, Tensioning mechanism. 2, Vibrator. 3, Ram. 4, Working hydraulic cylinders. 5, Movable crosshead. 6, Fixed crosshead. 7, Column. 8, Pumping plant. 9, Electric motor

* V. I. Vlasov, B. I. Petrov, A. P. Rogachevskii, V. A. Filatov (deceased), M. S. Sotskii and S. N. Shestakov took part in the experimental part of the work.

deformations of the specimens in relation to time, arrangements were made for an electro-dynamometer device and a method of measurement based on the recordings of wire resistance strain gauges.

The system of measurements is shown in fig. 2. The lower part of the die 1 is fastened to the baseplate of the vibration press, and itself forms a dynamometer, working in conjunction with the electronic magnifier 5 and the type MP-02 sliding oscillograph 6. The upper part of the die 2 is fastened to the crosshead 8, set in motion by the two rams 7 from the hydraulic system. The ram 9 is seated on bearings fastened in the crosshead 8 and the plate. At the top end of the ram 9 is fastened the vibrator 10, with the bottom end of the ram 9 pressing against the die 2.

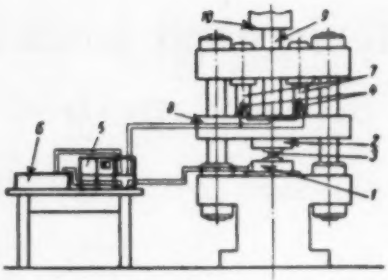
The operation and recording of the forces on the press are carried out in the following manner. The specimen 3 is placed on the die with the dynamometer 1. The crosshead 8, moving downwards, brings the upper die 2 into contact with the specimen 3. During subsequent movement, the gap between the die 2 and the crosshead 8 is taken up first of all, and then compression of the specimen 3 by the hydraulic system takes place.

The relatively slowly changing force during the compression of the specimen brings about elastic deformation of the rods of the dynamometer 1 to which are fastened the wire strain gauges (not shown in fig. 2). The wire strain gauges, connected to a bridge system, transmit an electric signal to the input of the amplifier 5. The output of the amplifier 5 is connected with the slide of the oscillograph 6 where the electric signal is recorded on a film.

On attaining the maximum force set from the hydraulic system, the vibrator 10 is switched on, under the action of which the ram 9 starts to carry out oscillations in the vertical direction, thereby applying impulses to the top die 2, as a result of which the specimen is additionally deformed. The dynamic loads deforming the specimen are recorded in a similar manner to that described above. The strain gauges 4 are intended to be an additional means of recording the forces in the rams of the hydraulic system.

For the measurement of the deformation of the specimen in relation to time a strain gauge was installed to measure the travel of the top die. This is not shown in fig. 2. The strain gauge provides recordings of the movements of the top die relative to the bottom one, thereby measuring the change in the height of the specimen being compressed in relation to time.

The body of the dynamometer, made from steel 45, consists of the base, the cradle and the elastic fins. The dynamometer is rigidly fixed to the column of the press by its base. In the cradle is



2 *System of measurements during stamping with vibration*

fastened an insert die. Under the action of the forging force the cradle is moved in relation to the base as a result of the deformation of the elastic part of the body of the dynamometer.

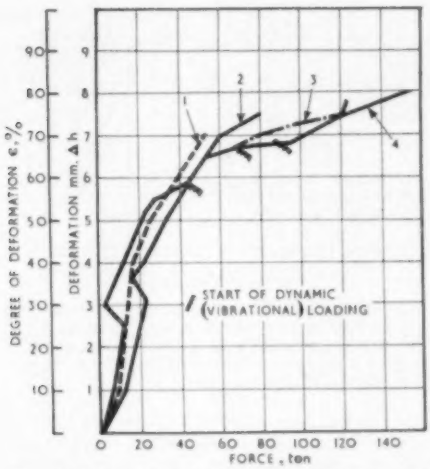
The elastic system of the dynamometer, consisting of a vertical stalk and a horizontally placed diaphragm, allows the cradle to move only in the vertical direction. The parameters of the elastic elements of the body of the dynamometer are so calculated that the value of the elastic movements at a loading of 100 tons does not exceed about 0·02 mm.

For recording the movements of the cradle use is made of three load cells, which press against the bottom of the cradle, being fastened in the flange. The body of the load cell has a thin-walled section —the stalk, on to which are fastened wire strain gauges with a resistance of 200 ohms each. The tapered end of the load cell is fastened by screws in the cradle of the dynamometer. The cylindrical, thickened end is fastened in the flange.

Two wire strain gauges are located at opposite sides of the thin-walled stalk and along its axis, and two at right-angles to it above the first two. The strain gauges are insulated against water by a layer of a mixture of paraffin with rosin, 1·5–2 mm. thick.

The six working strain gauges and the six compensating gauges fastened on the three bodies form two arms of the input side of a Wheatstone bridge. Thereby the operating strain gauges, by taking part in the deformation of the thin-walled section of the stalk, transmit an appropriate signal to the input side of the magnifier. The compensating strain gauges ensure the elimination of disturbances connected with the action of temperature on the electrical and mechanical elements of the dynamometer system.

The travel strain gauge, which provides a recording of the degree and rate of deformation of the specimen in relation to time, takes the form of an elastic ring, manufactured from 65G steel. The ring is fastened to both halves of the die, and is elastically deformed within the limits of 20 mm.



3 *Graph of the relationship between deformation and force during the compression of specimens of 25-mm. dia. and 10-mm. high in VD-17 alloy under conditions of a combination of static and vibrational loads*
1, P_{st} = 12·5 *tons*, ω = 940–950 *vibrations/min.* 2, P_{st} = 4·5 *tons*, ω = 940–990 *vibrations/min.* 3, P_{st} = 70 *tons*, ω = 990–1,000 *vibrations/min.* 4, P_{st} = 90 *tons*, ω = 1,010–1,020 *vibrations/min.*

The deformation of the ring is recorded by means of wire strain gauges, fastened to the inner and outer surfaces of the ring and forming two arms of a Wheatstone bridge.

By means of the elastic ring in conjunction with the electrical strain gauges, recordings are made of curves of the relationship between travel and time on the film of an oscillograph. As a result of calculation of these curves, the values of the velocity and degree of deformation of the specimen were recorded at individual moments of time, and likewise various characteristics of the process of plastic deformation were established.

Calibration of the equipment was carried out before it was placed on the machinery, and directly in its working position.

Plastic deformation

The majority of the experiments were carried out by recording the forces and deformations in relation to time under the various working conditions of compression, in the form of oscillograms.

The fundamental relationships which are the starting point for the construction of the other important parameters were shown to be those of force-time and deformation-time, which were determined directly from the oscillograms. About 220 graphs were constructed, all of which may be split up into five groups:

(1) Compression of the specimen by a static force.

(2) Change in the force and deformation in relation to time during vibrational application of the load (a very small part of the deformation of the specimen was carried out by means of static force, preceding the vibrational compression).

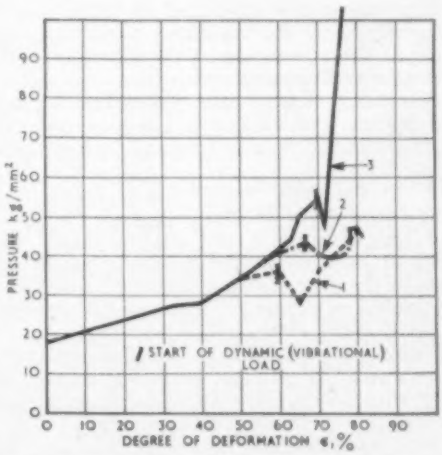
(3) The same as in (2) above, but in this instance almost the whole of the deformation of the specimen was carried out by means of vibrational loading.

(4) Compression of the specimens on a stamping press.

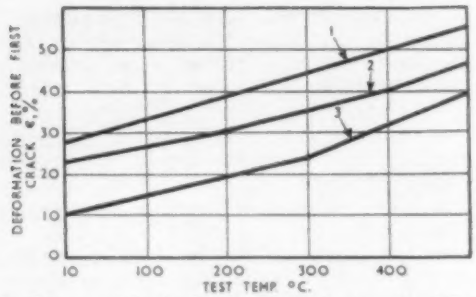
(5) Compression of the specimens under conditions of ' pure ' vibrational loading. By the term ' pure ' vibration is meant a process whereby the deforming stress is transmitted directly by the ram of the vibrator to the metal being deformed, so that $P_{st} = 0$.

The relationships between the deformations of the specimens and the deforming forces are presented in fig. 3. These relationships are different for the various materials tested and the various methods of application of the load (static, vibrational, static and vibrational). Thus the curves presented show that an increase in the static force by comparison with the vibrational load is unfavourably expressed in the plasticity, and leads to an increase in the deforming force. This is obviously apparent from the fact that a specimen initially compressed at a force P_{st} = 45 tons and a lower force P_{vibr} attained a greater degree of deformation by comparison with a specimen compressed at P_{st} = 90 tons.

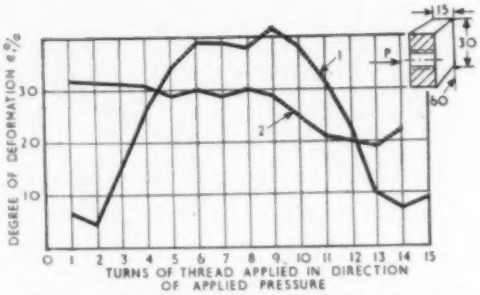
The relationship between pressure and degree



4 *Graph of the relationship between pressure and degree of deformation during the compression of specimens of 25 mm. dia. and height 20 mm. in VD-17 alloy under conditions of static-vibrational operation*
1, P_{st} = 45 *tons*, ω = 970–980 *vibrations/min.* 2, P_{st} = 70 *tons*, ω = 990–1,000 *vibrations/min.* 3, P_{st} = 90 *tons*, ω = 960–1,000 *vibrations/min.*



5 *Diagram of the plastic properties of titanium alloy VT-2 during compression on different machines*
1, *On the vibration press.* 2, *On a stamping press.* 3, *On a hammer*



6 *Distribution of the actual degrees of deformation during hot compression (480°C.) of rectangular specimens, 15 × 30 × 60 mm., of AK-6 alloy on different machines*
1, *On a mechanical forging press with a force of* 1,300 *tons* ($\varepsilon = 25\%$). 2, *On the vibration press* ($\varepsilon = 26{\cdot}3\%$)

of deformation is presented in fig. 4. The value of the pressure was determined by dividing the operating force by the relevant area of the cross-section of the specimen. The area was determined by calculation, for each value of the current height of the specimen, based on constancy of volume of the specimen during compression.

In fig. 4 the graphs relate to compression of specimens during two sets of working conditions: static and vibrational. Thus the values of the pressures for the final degree of deformation are less for those specimens where the vibrational loading was commenced at lower values of P_{st}.

Consequently the replacement of static loading by vibrational loading promotes an increase in the plastic properties of the material during the mechanical working process.

The experiments conducted to determine the relationships of the deforming forces and the shape of the cross-section of the specimen showed that the most favourable cross-section of a specimen, which renders it more easily susceptible to plastic deformation (compression) and requires the minimum deforming force, is a circular cross-section.

Macro- and micro-structure

Investigations were carried out of the macro- and micro-structures, and determinations were made of the degree of deformation ε in individual areas of the cross-section of a specimen, and of its mechanical properties. Comparing the specimens of AK-6 alloy, obtained by compression on the vibration press and on an ordinary mechanical press, it may be seen that in the first instance the deformation of the specimens attains a greater value without the appearance of the first crack ($\varepsilon > 70\%$).

From fig. 5, in which curves 2 and 3 are borrowed from papers of A. A. Nikol'skii, may be seen the increase in the plastic properties of titanium alloy VT-2 under conditions of working the alloy on the vibration press at various temperatures.

It was also established that during the deformation of aluminium alloy VD-17 in the cold state by the vibration method the plastic properties are increased by about 30–40%, and during the deformation of the titanium alloy VT-2 in the hot and cold states the properties are increased by approximately 25% by comparison with the plastic properties during deformation on a forging press, and by about 100% by comparison with deformation on a hammer.

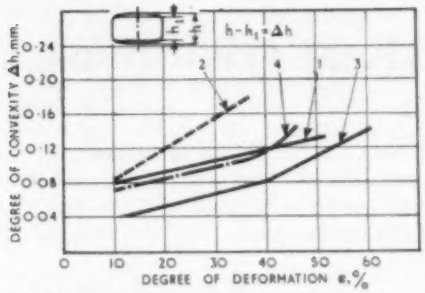
During investigation of the micro- and macro-structure of the specimens it proved possible to establish that during vibration conditions are created for more favourable distribution of deformation throughout the volume. The fibres of the specimen compressed on the vibration press are directed almost perpendicular to the plane of the end face over the whole of the cross-section. The folding action over the end faces produced here is considerably less, *i.e.* the deformation proceeds more homogeneously. The microstructure of the specimens of AK-6 alloy was also more homogeneous after recrystallization heating as a result of compression on the vibration press.

One of the important characteristics for comparison is the grain size of a deformed specimen after the recrystallization period. Experiments conducted to determine the distribution of the grain size over the height of specimens of VD-17 alloy showed that the most homogeneous and fine structure is obtained on the specimens compressed on the vibration press with the use of a lubricant.

During compression on hydraulic and crank-drive forging presses, the grains produced are coarser, by as much as 100%, and more inhomogeneous over the height of the specimen than occurs during compression on the vibration press.

The inhomogeneity of the deformation was studied on specimens into which screws had been inserted.

In fig. 6 are presented two curves relating to the



7 *Relationship between the convexity of the end faces, the conditions of deformation and the degree of deformation (specimens of AK-6 alloy, compression in the cold state)*
1, Compression on the vibration press without lubricant. 2, Compression on a stamping press without lubricant. 3, Compression on the vibration press with the use of a lubricant. 4, Compression on a stamping press with the use of a lubricant

compression of rectangular specimens, 15 × 30 × 60 mm., of AK-6 alloy in the hot state.

As a result it was established that, on the vibration press under conditions of ' pure ' vibration or with preliminary compression by means of hydraulic pressure, a more homogeneous distribution of the deformation of the metal is obtained.

The hardness distribution on the surface and in the centre of the specimens deformed in the cold state was more homogeneous as a result of deformation on the vibration press.

Mechanical properties

The mechanical properties of the specimens of AK-6 alloy after compression on the different machines are shown in table 1. After compression

TABLE 1 *Mechanical properties of specimens of AK-6 alloy after cold deformation and subsequent heat treatment*

No. of specimens tested	Machine on which compression was carried out	ε %	Mechanical properties		
			σ_b kg./mm.²	σ_T kg./mm.²	δ %
4	Vibration press-hammer	20	44·0	32	19
5		26–29	43·0	32	19
7		36–39	44·0	33	19
2	Hydraulic press	20	42·0	30	17
2		29	44·0	31	15
2		35	41·5	27	16
2	Stamping press	21	40·0	30	16
2		26	43·0	31	18
4		39	42·0	31·5	19·5

the specimens were subjected to heat treatment by quenching and tempering subject to standard conditions. During mechanical tests on an IM-4R machine, the ultimate tensile strength σ_b, the yield strength σ_T and the relative elongation δ were determined.

As is evident from the table, the mechanical properties of the specimens produced by vibration forging are more uniform and in their absolute values are not less than the mechanical properties of the specimens produced on hydraulic and mechanical presses.

The dimensional accuracy of the deformed specimens was characterized by the value of the convexity of the end faces and the side surface of the deformed specimens. The vibration method of deformation in all instances promoted an increase in accuracy on the end faces of up to 50% (fig. 7) and a reduction in the convexity of the side surface of up to 60%.

At the present time the process of vibration deformation is in a state of development for mass production.

Conclusions

An overall assessment of the results obtained permits the conclusion to be drawn that the process of vibration forging has beneficial aspects. By the vibration method of deformation the following advantages are ensured:

1. More even deformation throughout the volume of the deformed metal is ensured.

Under conditions of frequently changing (vibrational) loadings plastic deformation is concentrated on a larger quantity of microscopic volumes than during static applications of load. By this method, thanks to the intermittent loading, there is also a decrease in external friction, and conditions are created for more homogeneous distribution of the stresses throughout the volume, ensuring favourable conditions for the development of the processes of plastic deformation.

2. There is a reduction in friction on the contact surfaces of up to 60%.

3. There is an increase in the plastic properties of the material being worked of up to 40% in the instance of deformation of light alloys and titanium alloys, structural steels, etc.

4. There is a reduction in pressure of 50–100%, which brings about an increase in the working life of the dies and a decrease in the required capacity of the equipment.

During the forging of billets for components (turbine blades) in VD-17 alloy, it was established that the vibration method permits the production of components with a tolerance along the blade after polishing of ±0·05 mm. and with a higher surface quality than on mechanical forging and stamping presses.

By means of the investigations carried out, the practical need has been shown for special vibration forging machines for the mechanical working of metals in mass production, preferably for finishing operations, such as gauging and die-stamping.

Protective coatings for heat treatment

This article discusses the effectiveness of protective coatings applied to steel and superalloy parts to be heat treated, in facilitating scale removal or preventing oxidation. It is claimed that their use can result in economies in heat treating where production quantities are low but surface protection of parts is needed*

WHEN HEAT TREATED, steels, and to a still greater extent the newer cobalt and nickel-base alloys, may form scale which resists removal by conventional acid pickling. Descaling often requires long pickling periods, inducing harmful effects such as intergranular attack, selective etching and excessive metal loss.

To prevent surface oxidation during heat treatment, special facilities are being used of which molten salt baths, atmosphere and vacuum furnaces are most prominent. Although these are highly effective for bright heat-treating steel and heat-resistant alloys, they are costly, require rigid process controls, and are only economical for high-production quantities.

In the aircraft industry, high-production quantities are seldom experienced, and the purchase of special heat-treating equipment is often not warranted. At Boeing, protective coatings have been used successfully on such parts as nozzle boxes of Hastelloy X for turbines, spars of precipitation hardening alloys, ducts of Type 321 stainless steel and on thin sheets for airframe skins. The coatings, which decrease metal losses during pickling and make it easier to remove scale, can be classified as either scale conditioners, mechanically bonded protective coatings, or plated and diffusion coatings.

The specific coating selected for a given material is dependent on many factors. Certain alloys form peculiar chemical and physical types of scale which may be chemically resistant to pickling. Other alloys contain phases from which scale is difficult to remove. Consequently, they may suffer severe intergranular attack during long pickling periods. Generally, long exposure at high temperature will yield a tenacious scale, but other factors, chiefly metallurgical, can moderate this effect. Thus, a tempering scale on a hardened steel is more difficult to remove than a scale produced during austenitizing.

* Based on a paper in *Metal Progress*, June, 1961, by E. L. Stone and L. Albertin, project chief and research engineer, respectively, Metals Unit, Manufacturing Development Section, Boeing Airplane Co., Seattle, Wash.

Surface preparation

The most important requirement in protective coating technology is cleanliness of the surface to which coatings are applied. The chemical and physical nature of a metallic surface has a very marked effect upon the quality of any coating that may be used to protect it. Consequently, the production of heat-treatment coatings of high quality is dependent upon the thorough pretreatment of the surface of the base metal by degreasing and descaling.

Scale conditioners

New scale conditioning coatings and methods of application have been developed recently. Of these, two have been thoroughly tested at Boeing and have received considerable usage. These include the oxidation-inhibiting coatings consisting of silicone oil or grease, and a clay-suspension type. The former coating was developed for stainless steels, but it may also be applied to other metals (although it has thus far been ineffective on titanium). The latter coating is predominantly used on nickel and cobalt-base alloys.

Silicone coating compounds with a viscosity ranging from 20 to 60,000 centistokes have proved satisfactory, but 50 centistokes is the optimum for coating applications. Any silicone fluid or grease is usable, but the dimethylsiloxane polymer is the most readily available and effective. The dimethylsiloxane is brushed on in the heat-treating shop or, for large sheets, a paint roller is most convenient for rapid application. The coating remains oily and cannot be scratched off. During heat treatment it decomposes and emits a fume. Silicone-coated parts can often be stacked together without greatly affecting the coating's performance. However, with alloys yielding more difficult scales, maximum coating protection is obtained by freely suspending and separating the parts.

Pickling is carried out in an acid bath containing

15–35% HNO_3, 1·5–8·0% HF, and water. When a silicone coating is applied to stainless steel before annealing, the total metal loss from heat treatment and descaling is about 0·1–0·2 mil. After three annealings (applying a coating before each) total metal loss is about 0·4–0·6 mil with only one descaling step required.

Without a coating, the total metal loss is 0·5–1·5 mil. During three annealing treatments (descaling after each), an uncoated surface will sustain a total loss of 1·5–4·5 mils. The use of the silicone coating during annealing reduces final pickling time to 4–10 min. (Usually, it takes up to 15 min. to remove the cumulative scale formed during three annealing treatments.) In general, pickling time on a coated material is about one-fifth to one-tenth of that for a non-coated material.

By first dipping parts in an alkaline-permanganate scale conditioner, it is possible to remove cumulative scale formed during solution treatment and precipitation hardening from steels such as 17-7 PH and PH 15-7 Mo. This can be done with inhibited hydrochloric acid, a mild pickling treatment that appears to be a safe way of avoiding intergranular attack on certain sensitive alloys.

Silicone coatings offer a number of cost-saving advantages to heat treaters. They can be applied in the heat-treatment shop, thus saving time. Coating thickness is not critical and protection is achieved even with careless application. In addition, a very clean surface is required only when a mild pickling solution such as inhibited hydrochloric acid is used.

Clay coatings for superalloys

Clay suspension coatings can be applied with success on many alloys, but they are most effective when used on nickel and cobalt-base super-alloys. The coating is applied in a spray booth with adequate ventilation. Spraying is usually controlled so that a coating thickness of 0·2–0·5 mil is obtained. When cured, the coating has a reasonable dry strength, but careful handling is necessary in transporting the parts to the furnace to prevent damage. The coating requires a very clean surface and should be uniformly applied.

Typical descaling times and metal losses for three superalloys are shown in table 1. The data show that effectiveness of dry coatings varies with the alloy. For instance, without the coating it would be almost impossible to descale Hastelloy X. With René 41, it does not save pickling time, but it saves from 0·2–0·3 mil of metal.

Mechanically bonded coatings

The method of application of a metallic or ceramic coating for metal protection at elevated temperature has a significant influence on its character. Thickness, uniformity, composition, density, continuity and adherence are affected by the coating process, and the quality of protection and cost are related to the method of application and type of coating used.

Mechanically bonded coatings are applied by hot dipping, brushing or metal spraying. Not all coatings are readily applied by all methods, but usually, for a given metal, one or more processes are equally practical and economically feasible.

In the manufacturing sequence for titanium alloys, elevated temperatures are frequently required, for forming and heat treating. To reduce warpage during the thermal treatment, heat-treating fixtures of heat-resistant alloys are employed. Although special alloy tools could withstand the elevated temperatures, they are costly and often difficult to obtain in quantity. As a substitute, mild steel is frequently used with an adequate coating to protect it from oxidation at elevated temperatures. Coatings of nickel-chromium-boron alloys and nickel-chromium alloy covered with

TABLE 1 *Typical descaling times and metal losses for clay-coated superalloys*

Clay suspension used	René 41		Haynes Stellite 25		Hastelloy X	
	Pickle A*	Pickle B†	Pickle A	Pickle B	Pickle A	Pickle B
			Time to descale, minimum/metal loss, mils			
Yes	2/0·3	6/0·2	45/0·7	70/0·6	15/0·4	40/0·3
No	15/0·5	40/—	45/0·8	110/‡	135/—	60/‡
Yes§	8/0·5	40/0·3	30–45/0·5	105/0·5	10/0·3	50/0·2
No	25–30/0·7	30/0·4	45–75/0·7	115/0·6	180–240/0·6	145/‡
Yes§	16/0·5	40/0·3	30–45/0·6	90–105/0·5	10/0·2	60/0·2
No	25–30/0·8	30/0·6	45–75/0·8	115–130/0·8	120–240/0·7	145/‡
Yes§	16/0·6	40/0·3	30–45/0·6	105/0·7	15/0·3	60/0·2
No	25–30/0·9	30/0·6	45–75/0·9	115/0·8	180–240/0·8	145/‡

* Pickle A: 34% hydrofluoric, 5% nitric acid.
† Pickle B: 4% hydrofluoric, 20% nitric acid preceded by scale conditioning in an alkaline-permanganate solution.
‡ Incomplete scale removal.
§ Two coats (total thickness: 1 mil).

a layer of aluminium oxide will give adequate protection for mild-steel ageing fixtures. For prototype quantities, aluminium oxide alone will give economical and adequate protection.

These particular coatings are applied by a flame spray process using the protective materials in wire or powder forms. Tools to be coated are prepared by vapour degreasing and grit blasting. The most economical protective coating has a thickness of 0·003–0·005 in. All coatings except aluminium oxide must be baked in a reducing atmosphere. Tools are loaded into the furnace which is operating at 980°C. The temperature is then raised to 1,040°C. and the tools are held at temperature for 5 min. after which they may be removed and cooled in air. Finishing is done with buffing and grinding wheels to remove 'orange peel.' The aluminium oxide coating is surface finished with No. 240 emery paper.

In the heat treatment of titanium alloys and stainless steels, coatings also serve to inhibit contamination. Various coatings have been recently developed which are of the pop-off type or which can be removed by chemical solutions. Two such ceramic coatings and one aluminium paint (aluminium powder suspended in silicone oil) have been tried with varying success at Boeing. One of these ceramic coatings was of a glass type, the other was a pop-off coating. Ceramic coatings are applied by spraying and the aluminium paint is brushed on. The former can vary in thickness from 4–10 mils and can be dried at room temperature. Aluminium paint requires a drying temperature of 200°C. and a baking temperature of 650°C. for a total of 24 h. The glass-type ceramic coating is removed after heat treatment by a 20-min. immersion in a 15% sodium hydroxide solution; aluminium paint requires a total of 1 h. in alkaline and pickling solutions. The pop-off coating is removed by quenching in water.

Of the three coatings, the glass-type ceramic gives the best protection against oxidation. In addition, it requires a production flow time of only 1 h. compared to 30 h. for aluminium paint. The pop-off coating is the least successful because frequently pop-off properties are ineffective, and removal of the residual coating by pickling solutions is difficult.

Borax controls decarburization

Another application of heat-treatment coatings lies in the protection of high-carbon tool steels which tend to decarburize when heated to the hardening temperature range. It has been found that a borax film, applied as a saturated water solution, is helpful in controlling decarburization. The unheated parts can be immersed in the solution at 82–100°C., or the solution can be applied with a brush or spray. Pieces so treated are heated as usual, but care must be taken to preserve the borax during handling.

Still another method of protecting finished parts during hardening is to apply a coating of copper paint which can be brushed or sprayed on. After drying, a protective coating of copper remains.

Plated and diffusion coatings

One of the best examples of a plated coating is the use of copper to protect selected areas on parts that are to be case hardened. This widely used method finds application where production warrants the expense of installation and operation.

Copper plating is effective with most carburizing compounds, although with some, it does not prevent carbon penetration. In addition, there is considerable difficulty in depositing the copper plate in recessed areas.

Two methods may be employed when using copper plate. The entire piece is plated and the copper is removed by machining or grinding it from that portion to be hardened, or suitable protective paints are used to mask off the areas not to be copper plated. In the usual method, a baking japan or lacquer is painted on the area to be hardened. It is baked or dried, and the part then plated. In the subsequent carburizing operation, the japan or lacquer burns off, permitting the carburizing gases to contact only those areas which are to be hardened. Masking may also be done with rubber or with a wax stop-off.

Bright annealing

One technique for protecting steel and superalloys during heat treatment is based on thermal reduction of metallic halides which produces a thin skin on the parts. Used widely in France and now being investigated at Boeing, the process has proved effective in bright annealing treatments.

To apply the protective layer, the parts to be bright annealed are put into retorts containing small amounts of ammonium fluoride and powders of chromium or nickel The retorts are closed by welding except for an opening for escaping gases. When the parts are treated at elevated temperature, the ammonium fluoride reacts with the metal powders and is dissociated. A thin skin of low-volatility fluoride is formed on the surfaces of the parts. This fluoride is reduced at higher temperatures forming a reducing atmosphere. As a result, the parts are usually bright with little oxidation of the surface. Several cobalt and nickel-base alloys have been treated in this manner at Boeing with excellent results.

Fuel efficiency in steel heat-treatment practice

G. A. BLACKWELL, M.Inst.F., M.Inst.Gas E.

The object of the following notes is to explain the general principles involved in achieving efficient fuel utilization in steel heat-treatment practice. Many types of furnaces are used and numerous factors have to be considered, some quite distinct from fuel economy. Generally, however, the guiding principles of practice are common to them all and those discussed apply to all furnaces. It cannot be over-emphasized, however, that the most important function of any heat-treatment furnace is to produce a satisfactory product and other considerations, such as fuel economy, must always be subordinate to this*

FUELS USED FOR HEATING heat-treatment furnaces fall under four headings, namely: (*a*) solid fuels; (*b*) gaseous fuels; (*c*) liquid fuels; and (*d*) electricity.

Solid fuels Solid fuels in the form of coal and coke can be applied efficiently and smokelessly to heat-treatment furnaces by the use of mechanical stokers. Running costs, compared with alternative fuels, can be low, but the difficulty of controlling operating conditions to within the fine limits often required in modern heat-treatment practice is a serious disadvantage.

Pulverized coal has improved application, but does not compare favourably with gaseous or liquid fuel for flexibility of control. The trend in practice is towards the replacement of solid fuel firing by more controllable forms of heating.

Gaseous fuels Included in this category is town's gas, coke-oven gas and producer gas. Gaseous fuels are used extensively for the firing of heat-treatment furnaces. They are in the ideal state for intimate mixing with air to give complete combustion with the minimum of excess air, and the gas and air mixture can be accurately controlled to give the rate of heat liberation required with the desired furnace atmosphere.

Town's gas is perhaps the most suitable of all fuels for application to heat-treatment furnaces by virtue of its consistency of quality, constancy of supply and ease of control. Its high purity renders it particularly useful for special applications where sulphur would be injurious. The relatively high price of this fuel can often be offset by reduced maintenance costs, extended refractory life and increased furnace availability.

Liquid fuels Liquid fuels used for heat treatment are gas oil, light and heavy fuel oils and coal tar fuels. These fuels have many of the advantages associated with gaseous fuels, and with the exception of producer gas the relative cost per therm is considerably cheaper.

Smokeless combustion of liquid fuels cannot be achieved without an excess of air and this makes it difficult to obtain the reducing atmospheres sometimes required in practice. From the metallurgical aspect the high sulphur content of liquid fuels must be taken into consideration, as this may have a deleterious effect on the work.

Electricity A wide variety of electric batch and continuous furnaces are used for steel heat treatment. They are specially suitable for certain low-temperature applications and fans are often incorporated in the design in order to improve rate of heating and uniformity of temperature.

The only factors affecting efficiency in electric furnaces are heat-transfer rates, furnace insulation and loading. All other matters regarding excess air, preheating, waste-heat recovery, etc., do not apply because there is no positive gas flow.

Typical characteristics of fuels normally used in heat-treatment practice are given in table 1.

*Article based by the author on his lecture given at the Birmingham College of Advanced Technology last January in the series 'Modern developments in the theory and practice of steel heat treatment.' The author is with the National Industrial Fuel Efficiency Service. Articles based on other lectures in the series will be published in future issues of METAL TREATMENT.

General principles of combustion and the heating values of fuels

Combustion The chief constituents of solid, gaseous and liquid fuels are carbon and hydrogen, which are present either as elements or in chemical combination with each other or with sulphur or oxygen.

During combustion, carbon, hydrogen, carbon monoxide and hydrocarbons chemically combine with the oxygen in the air and the resultant products of complete combustion are carbon dioxide (CO_2) and water vapour (H_2O); heat is always generated during the process.

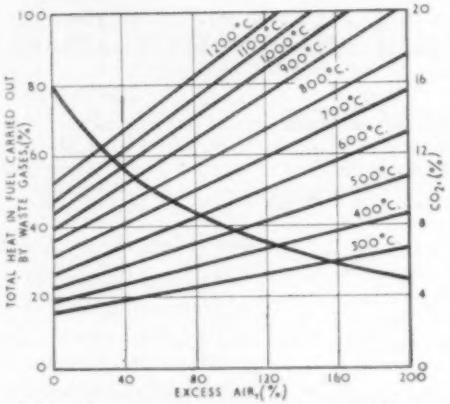
Since combustion cannot be effected without air, and air is composed approximately of one-fifth oxygen and four-fifths nitrogen, the products of combustion are always accompanied by large quantities of nitrogen. Nitrogen plays no part in the combustion process and is a diluent.

Optimum combustion efficiency is achieved when the fuel is completely burnt with the minimum amount of air. If there is a deficiency of air, the carbon in the fuel is incompletely burnt to form carbon monoxide and a considerable amount of potential heat in the fuel is lost.

Excess air In practice it is difficult to obtain complete combustion unless more than the amount of air theoretically required is used. This is due to the difficulty of bringing the oxygen in the air into intimate contact with the fuel during the comparatively short time it remains in the furnace.

Normally gaseous fuels can be burnt efficiently with very little excess air. With liquid fuels excess air requirements are in the order of 20/30% and for solid fuels an excess of 50% is needed.

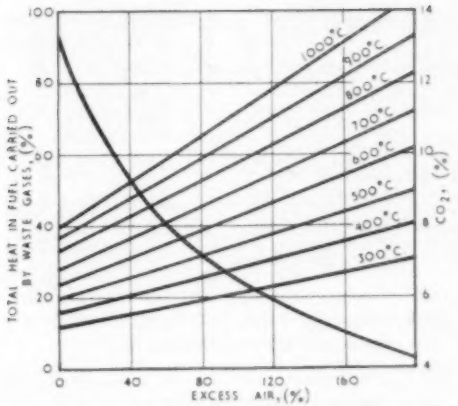
If air in excess of the normal requirements is used to burn the fuel, efficiency will be lowered and wastage occurs, because this excess will be heated and carried away as additional sensible heat in the waste gases. This effect of excess air on amount of heat carried away in the waste gases is illustrated in the graphs shown in figs. 1 and 2. From the radiating lines of flue-gas temperature shown the percentage of the total heat in the fuel that is lost can be read against varying percentages of excess air. Curves showing the percentage of CO_2 corresponding to various percentages of excess air are also given. In addition, excess air reduces flame temperature and adversely affects heat transfer. Consequently, the amount of air used should always be the smallest quantity that will enable the fuel to be properly burned in the prevailing conditions.



1 *Effects of excess air on amount of heat carried away in waste gases at various temperatures*

TABLE 1 *Typical characteristics of fuels used in heat-treatment furnaces*

	Town's gas	Producer gas	Fuel oil, 200 secs.	C.T.F. 200	Bituminous coal	Coke
Calorific value Gross B.Th.U.	475/cu. ft.	163/cu. ft.	18,900/lb.	16,250/lb.	11,100/lb.	12,500/lb.
Calorific value Net B.Th.U.	428/cu. ft.	150/cu. ft.	17,740/lb.	15,900/lb.	10,500/lb.	12,400/lb.
Air for theoretical combustion, cubic feet ..	4·06/cu. ft.	1·28/cu. ft.	184/lb.	163/lb.	131/lb.	134/lb.
Products of theoretical combustion, cubic feet ..	4·74/cu. ft.	2·07/cu. ft.	196/lb.	170/lb.	138/lb.	135/lb.
Maximum theoretical CO_2 content of dry waste gases, %	13·3	19·2	15·9	17·6	18·4	20·5
Excess air in good practice, %	10	10	20	20	50	50
Products of combustion, cubic feet	5·15/cu. ft.	2·19/cu. ft.	233/lb.	203/lb.	183/lb.	201/lb.
Average CO_2 content of dry waste gases, %	11·9	17·9	13·2	14·6	12·1	13·4



2 *Effects of excess air on amount of heat carried away in waste gases at various temperatures*

Table 2 shows the effect of excess air on flame temperature.

The nature of flame Flame is the effect produced when fuel gases and air are brought together under suitable conditions for them to burn.

The character of the heat transmission from the flame is dependent on the type of fuel used and the manner in which the fuel and air are mixed. For instance, flames may be shortened by more intimate mixing, or by increasing the proportion of air. Conversely, by delaying mixing or reducing the proportion of air present, flames can be lengthened.

The shape of the flame can be of great practical importance. For example, the heating characters of a long lazy luminous flame will be very different from the short flame produced by an air-blast burner.

With a luminous flame the degree of radiation to the furnace walls and load is increased considerably and this can often result in quicker heating up times and improved temperature uniformity. Also, as the volume of the flame is increased for a particular rate of fuel flow, the heat release per given volume of flame and its temperature is reduced.

The furnace controls should always be set to give the shape of flame most suitable to obtain the desired temperature distribution in all parts of the heating chamber.

TABLE 2 *Approximate effect of excess air on flame temperature*

Excess air (%)	Flame temperature (°C.)	
	Fuel oil	Town's gas
Nil	2,080	1,950
20	1,870	1,850
40	1,700	1,700
60	1,570	1,550
80	1,450	1,430

Calorific value of fuels It has been explained that heat is liberated during the combustion process.

The amount of heat made available by the complete combustion of a fuel is known as its calorific value (C.V.) and this depends on its chemical composition and in particular the amount of carbon and hydrogen present.

The C.V. is expressed as British Thermal Units (B.Th.U.) unit of fuel and normally the values are quoted either on a gross or net basis. The gross or higher C.V. represents the number of B.Th.U. developed by the complete combustion of the fuel and includes the latent heat given up by condensation of the water vapour present in the combustion products. In furnace practice condensation never occurs and the latent heat is lost. Thus the lower or net C.V. is obtained by deducting from the gross C.V. the latent heat absorbed by the formation of steam during combustion.

When heating values of various fuels are being compared, or when figures of thermal efficiencies are given, it is important to know whether they have been based on net or gross C.V.

FACTORS INFLUENCING THE EFFICIENCY OF HEAT-TREATMENT FURNACES

Design considerations

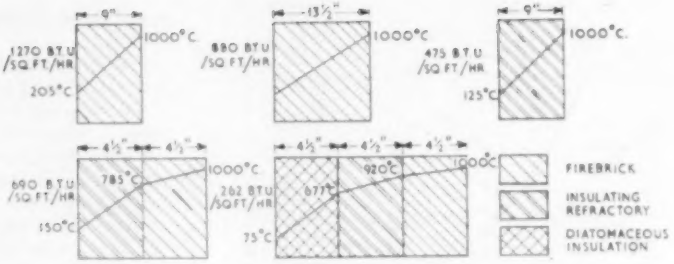
A furnace consists of a refractory-lined heating chamber in which the heat liberated by combustion is transmitted to the charge, a firing system, and an exhaust system through which the products of combustion are discharged. If solid fuel is the heating medium, an external brick-lined combustion chamber is required.

It is of primary importance that the designed capacity of the furnace is closely related to the required output, since one of the main causes of heat loss lies in incompletely filled furnaces.

The shape of the furnace chamber is also of vital importance and this should be so designed to permit the maximum amount of radiation to be transmitted to the work by the hot furnace surfaces.

The number, size and disposition of the burners require careful attention if rapid attainment of required temperature and uniformity of heating is to be achieved without flame impingement. The size and number of flue offtakes is equally important, and they should be located relative to burner positions to give a satisfactory hot gas flow pattern and to ensure optimum travel of the gases before their final discharge to atmosphere.

Special attention should be given to the design of the furnace door, for a badly designed door is inevitably a source of considerable heat loss. For example, a badly fitting door on a furnace having a



3 *Heat losses and temperature gradients in various homogeneous and composite walls*

gap 1 in. wide and 24 in. long along its top edge will give a heat loss of approximately 200,000 B.Th.U. h. due to escaping gases if the furnace is operating at 1,000° C. under normal pressure conditions.

Ideally an automatic closing force should be applied to a door and a simple method of achieving this is to allow the door to rise and fall on an inclined face.

Construction

The design of the furnace structural steel framework must be based on sound mechanical principles. Robustness is essential, for breakdowns or delays caused by steelwork having insufficient strength may well result in serious production losses and fuel wastage.

The choice and use of the most suitable type of refractory and insulating material in the brickwork construction of the furnace has a vital influence on fuel economy. Before deciding on the type of bricks that should be employed careful consideration should be given to the following points:

(*a*) The maximum temperature to which the brick will be subjected.

(*b*) The physical conditions under which the brick will be used.

(*c*) The relative heat conductivity of the various bricks under consideration.

(*d*) Whether the bricks will be subjected to continuous or intermittent heating.

(*e*) The expansion that is likely to occur with various bricks when heated.

(*f*) The probable life of the bricks for the particular duty required.

(*g*) The comparative costs of the various bricks relative to the anticipated life.

Table 3 gives details of common materials, maximum service temperature, thermal conductivity, etc. It is important to remember that figures quoted are subject to variation according to the manufacturer.

The incorporation of insulating brickwork into the brickwork construction to a maximum extent is essential if heat losses from outside surfaces are to be reduced to a minimum. The usual practice is to back the dense firebrick internal chamber with insulating material of sufficient thickness.

With intermittently-operated heat-treatment furnaces efficiency is greatly influenced by the thermal capacity of the brickwork structure. For this reason hot face refractory insulation is now being widely used. This type of brick has a much lower bulk density than firebrick and as a result of the lower thermal capacity of the material and a reduced thermal conductivity figure, *i.e.* 2·7 B.Th.U./sq. ft./h./°F./in. compared with a figure of 8 for firebrick,

TABLE 3 *Typical data for refractory and insulating materials commonly used in steel heat-treatment furnaces*

Type of material	Max. service temperature (°C.)	Thermal conductivity (B.Th.U./sq. ft./h./°F./in.)	Bulk density (lb./cu. ft.)	Approx. costs of 9 × 4½ × 3-in. bricks (Stourbridge = 1)
	*	†		
Firebrick, 42–44% alumina	1,350–1,450	10·0	120–140	1·2
Firebrick, 35–37% alumina	1,250–1,350	10·0	120–130	1·07
Firebrick, 30–32% alumina	1,150–1,250	8·0	120–130	1·0
Sillimanite	1,500–1,600	12·0	150–156	10·0
Carborundum	1,700–1,800	112·0	130–155	28·0
Hot-face insulation, high grade ..	1,530	3·15	32–55	4·65
Hot-face insulation	1,350	2·7	32–50	2·87
Diatomaceous earth, insulation ..	870	1·1	25–30	1·2

* These temperatures vary with different manufacturers. † These values vary with the mean temperature.

considerable fuel economies can be usually achieved by its use.

Fig. 3 shows heat losses and temperature gradients in various types of wall and table 4 gives the thermal capacity and heat losses through different wall constructions under continuous and intermittent operation.

Types of heat-treatment furnaces

In selecting a furnace for heat-treatment purposes many important considerations have to be taken into account if optimum thermal efficiency is to be achieved. Method of loading, method of firing, temperature requirements, time cycles involved and any special metallurgical requirements are of primary importance when deciding on the most suitable type.

Furnaces are classified normally according to their methods of firing or loading, relationship of combustion products to the load or the time cycles involved. Often in practice furnaces can be classified under at least two headings. The following brief notes cover the classification of the majority of furnaces in use today:

1 *Batch type* In this type of furnace operation is intermittent and the load is withdrawn on completion of the heating cycle. The furnace idling times between loads must be kept to a minimum if excessive fuel wastage is to be avoided.

When furnaces are shut down for overnight or weekends the heat absorbed by the structure is a significant factor, for this is dissipated and lost when shut-down occurs.

2 *Continuous* As the term implies, in this furnace the load is progressively transported through the length of the furnace in accordance with the desired time/temperature cycle.

Generally thermal efficiencies are higher than with the batch type. This is due to reduced idling times, load recuperation and improved load factor.

3 *Muffle* With this type of furnace the load is heated in a separate refractory chamber known as a muffle. The products of combustion circulate around the muffle, but are prevented from coming into contact with the work. Controlled atmospheres can be introduced into the muffle to meet special metallurgical requirements.

Although muffles are generally constructed from highly-conductive material, thermal efficiencies are lower than with open flame furnaces.

In modern practice heat-resistant radiant tubes are often fitted into the working chamber. Combustion is completed within these tubes and here again the products do not come into contact with the load.

With the semi-muffle type of furnace a compromise has been made and the products of combustion are made to travel a reasonable distance before they are allowed to enter towards the top of the working chamber. By this method flame impingement is avoided and normally improved efficiency can be expected.

4 *Open-fired* In this type of furnace the products are discharged directly into the working chamber and come in contact with the load. This type is often further classified according to the method of firing, *i.e.* under-fired, side-fired or over-fired. Compared with a muffle, efficiency is higher with this type of furnace.

5 *Bogie-hearth* This is favoured for heavy masses and can be applied to either batch or continuous furnaces. The load to be heated is placed on the bogie, moved into the setting and withdrawn at the end of the cycle.

6 *Portable-cover* This consists essentially of a base containing a loading hearth, and a refractory-lined hood, which when lowered on to the base forms the heating chamber.

The accessibility of the base for loading and unloading is a very desirable feature of the design.

TABLE 4 *Thermal capacity and heat losses through vairous wall constructions from a furnace at* 1,000°C. *and having* 40 *sq. ft. of internal surface area and operating over a five-day weekly period* (*a*) *continuously*, (*b*) *intermittently*

Wall construction	Continuous operation 120 h./week			Intermittent operation 12 h./day 5 days/week		
	9-in. firebrick	9-in. hot face	4½-in. hot face + 4½-in. diatomaceous insulation	9-in. firebrick	9-in. hot face	4½-in. hot face + 4½-in. diatomaceous insulation
Heat loss through brickwork, therms/week	61·0	22·58	13·68	30·5	11·3	6·84
Heat storage loss after shut-down, therms/week ..	10·0	3·26	3·38	50·0	16·3	16·9
Total heat loss, therms/week	71·0	25·82	17·06	80·5	27·6	23·74
% reduction in heat losses by using insulation	—	63·5	76	—	65·5	70·5

The provision of an additional base can give a much more higher output at a lower cost, since the warm hood can be lowered on the base containing the fresh charge.

7 *High-temperature heat-treatment* This furnace is suitable for hardening tools of high-speed steel and normally consists of an upper preheating chamber and a lower finishing chamber. The waste gases from the lower chamber are used in the upper chamber for the purpose of preheating the work. If correctly used this furnace has high efficiency.

8 *Salt baths* These can be fired by either gas or electricity. When gas fired a preheating pot is often included in the plant in which the work is preheated by the waste gases prior to its immersion into the salt.

Work treated in salt baths has a clean, bright and scale-free finish and the constant temperature maintained in the bath gives accurate and uniform results.

Due to the corrosive nature of the salt, maintenance work on the burner equipment and bath must be regularly carried out.

Selection of burner equipment

As the majority of heat-treatment furnaces are now heated by town's gas or oil, consideration is only given under this heading to the burner systems utilized for these fuels.

A burner may be regarded as a means of converting the potential energy of the fuel into useful heat. The selection of the most suitable type at the correct capacity is of primary importance if maximum efficiency is to be obtained. Over-sized burners can result in ' over-gassing ' and incomplete combustion, smoke emission and excessive fuel consumption.

The number of burners to be used and their disposition in any particular furnace is also important in ensuring temperature uniformity in the working chamber.

Generally to be efficient a burner should have the following characteristics:

(*a*) It should be capable of regulation over a wide turn-down range without danger of flash-back.

(*b*) Flame stability at the burner nozzle should be satisfactory over the stipulated turn-down range.

(*c*) It should ensure intimate mixing of the fuel and air to give rapid and complete combustion.

(*d*) It should be capable of easy adjustment so that the desired furnace atmosphere can be obtained.

(*e*) It should be constructed so that routine maintenance can be easily undertaken.

Brief notes on the various types of burners usually employed for heat-treatment work are given.

Gas-burner systems

Gas burners are generally of simple construction and easy to maintain and adjust. Efficiency is increased if gas pressure remains constant and the installation of a governor on the gas line is always recommended.

The burners are classified as follows:

1 *Neat or post-aerated* All the combustion air in this system is supplied as secondary air.

This burner is simple in design, consisting essentially of a jet from which gas is ejected. It is capable of giving high rates of heat input and a very good turn-down range can be obtained.

Flame impingement on to cold surfaces must be avoided, otherwise sooting and incomplete combustion will occur. It has wide application on heat-treatment furnaces.

2 *Pre-aerated or Bunsen* With this system a proportion of the combustion air is entrained with the gas as primary air. The remaining secondary air is supplied at the burner head.

These burners are used extensively for heat-treatment purposes and are available in sizes up to 600 cu. ft./h.

Care must be taken when setting the primary air slide on this type, for it is liable to backfire on low consumptions if this is opened too much.

3 *High-pressure* Generally these burners operate at a gas pressure of 1–5 lb./sq. in. and the air for combustion is usually supplied in the form of secondary air.

The application of this type of burner to heat-treatment furnaces is small, the chief disadvantage being the initial and running costs of the compressor.

4 *Air-blast* In this type of burner the air is used to entrain the gas. The air pressure does not normally exceed 2 lb./sq. in.

The advantage of this system is that air and gas can be proportioned to give satisfactory air/gas ratios. The high velocity obtained from this burner necessitates the use of a burner tunnel or a flame-retention nozzle to prevent the flame from leaving the burner port.

It has a wide application on all types of heat-treatment furnaces.

Oil burner system

In burning liquid fuels it is essential that the oil be delivered to the burner at the correct viscosity for atomization, *i.e.* 100 secs. Redwood No. 1, and at a suitable pressure for any particular application.

Oil burners are usually classified according to the atomizing medium and the types normally used in heat-treatment practice are as follows:

1 *Low-pressure air* These burners are designed

to work at air pressures of between 12 and 28 in. w.g. and are supplied with air from a single-stage fan. The oil pressure required is usually about 5 lb./sq. in.

This type of burner is used extensively on heat-treatment furnaces where the primary air is not heated above 500°F. It is reliable and efficient, but its turn down range is rather limited.

2 *Medium-pressure air* These are supplied with air from a rotary-type compressor at pressures between 2 and 15 lb./sq. in. Only a small proportion of the combustion air is supplied at this pressure for atomizing the oil (usually about 5%), the remainder being induced or supplied by a fan at a pressure of a few inches w.g.

With this arrangement a high turn-down ratio can be achieved without loss of combustion efficiency. A further advantage is that the bulk of the combustion air can be preheated to as high a temperature as possible.

3 *High-pressure air* Air pressure in excess of 15 lb./sq. in. is required for these burners and this necessitates the use of a compressor which is costly to install and operate.

As with the medium-pressure air burner, about 5% of the high-pressure air is used for atomization and the remaining is either induced or provided by a fan.

The burner is normally of simple design and it is used where a high velocity is needed to give the desired flame length or shape.

A burner that is now being increasingly used on heat-treatment furnaces is the self-proportioning type. These can be utilized with either oil or town's gas and in either case combustion air at pressure between 12 and 28 in. w.g. is employed.

The burner is regulated by a single control and once the air/fuel ratio has been set the output of the burner can be altered by moving the single lever control. Thus a satisfactory air/fuel ratio is obtained over an approximate turn-down range of 5 : 1 and combustion efficiency is maintained.

Operation

Control of heat input The rate of heating is an important factor in most heat-treatment operations, and the fuel and air supplies should be regulated to match the time/temperature requirements. Thus the control valves should be capable of easy regulation.

Too slow heating increases furnace losses; too fast heating can result in incomplete combustion, excessive furnace pressure and high flue gas loss.

Combustion control To achieve optimum combustion efficiency it is essential to burn the fuel with the minimum amount of excess air.

The adverse effect on combustion and furnace atmosphere control of too much air and the loss of heat that occurs through air deficiency has been previously discussed.

It cannot be too highly stressed that unless special furnace chamber atmospheres are required every endeavour should be made to maintain satisfactory air/fuel ratios over all stages of operation by careful adjustment of fuel and air controls.

Combustion efficiency can always be checked by analysing the waste gases with an Orsat apparatus or CO_2 indicator. This will indicate the CO_2 content in the waste gases and be a guide to the quantity of air being used.

Furnace pressure For ideal conditions the pressure in the working chamber must be at atmospheric, or only very slightly in excess of atmospheric, at all rates of heating. Negative pressure conditions permit the inleakage of cold air, which cools the furnace, creates cold spots, increases waste gas losses and drastically affects furnace atmosphere conditions. Excessive pressure may retard combustion development and will increase losses by flame and hot gas emission through the door and openings.

Balanced pressure conditions can be maintained by careful adjustment of flue dampers. The function of a damper is to regulate the draught requirements for the various rates of heat input.

Correct regulation of the damper is of extreme importance if efficient fuel utilization is to be achieved, but it is often the most neglected part of the furnace and its maladjustment is frequently the cause of considerable fuel wastage.

In practice, manual operation of the damper to meet the changing requirements of the heating operation is difficult. This is particularly so with oil- and gas-fired furnaces which operate under high/low conditions.

Temperature control With almost any heat-treatment furnace the maintenance of a close time/temperature control is essential to bring about the required physical changes in the steel.

In a simple form this may merely mean the provision of an indicating pyrometer for the operator's guidance. He would then have to make frequent adjustments to the fuel input to obtain the desired heating cycle and temperature uniformity.

Apart from a serious effect on work quality, overheating means fuel wastage. Comparatively few heat-treatment furnaces operate nowadays without adequate temperature control equipment.

Instrumentation

Instrumentation is being used to an increasing degree on heat-treatment furnaces for the following reasons:

(*a*) To ensure that the desired time/temperature cycle is achieved.

(*b*) To ensure that the required furnace atmosphere is maintained.

(*c*) To ensure that the fuel is used economically.

Briefly, instruments and control equipment used fall under three headings:

1 *Automatic temperature control* The close control of the time cycle and temperature conditions is almost a necessity in modern steel heat-treatment practice.

The temperature controller adjusts the rate of heat input to meet temperature requirements through an automatic controller. Alternatively, where heating or cooling rates are important, an automatic programme controller can be used to control the furnace to a predetermined time/temperature schedule. Thus once the load has been charged into the furnace, heating up, soaking and cooling is automatically controlled.

2 *Air/fuel ratio controller* The air/fuel ratio controller maintains optimum combustion conditions through all rates of heating. Also where special atmospheres are required the controller can be set to give a predetermined air/fuel ratio as necessitated by the process requirements. Normally this type of controller is not installed on the smaller type of heat-treatment furnace.

3 *Furnace pressure controller* The object of the furnace pressure controller is to maintain the working chamber pressure as near to atmospheric as possible, so that hot gas losses due to excess pressure, and air inleakage due to negative pressure, can be kept to an absolute minimum.

With larger furnaces control is usually effected by automatic regulation of the main damper at the furnace waste-gas outlet. In practice, best results are generally obtained when the furnace operates with a slight positive pressure in the order of +0·01 in. w.g. in the working chamber.

On the smaller type of furnace the installation of a pressure controller cannot always be justified due to the capital cost involved. In this case a simple form of pressure control can be achieved by linking the damper to the temperature controller, which for this purpose should consist of a motorized valve. The damper is then open or shut according to the high/low dictation of the controller.

Where large quantities of fuel are used considerable economies can be expected from the use of a furnace pressure controller and capital outlay is normally speedily recovered.

Furnace loading

One of the most vital factors affecting efficiency is loading. There is a particular loading at which the furnace will operate at maximum thermal efficiency. If the furnace is underloaded a smaller fraction of the available heat in the chamber will be taken up by the steel and therefore efficiency will be low.

The best method of loading is generally obtained by trial—noting the weight of material put in at each charge, the time it takes to reach temperature and the fuel used. Every endeavour should then be made to load furnace at the rate associated with optimum efficiency.

The fuel consumption to maintain a simple batch-type furnace at 1,000°C. when empty is in the order of 60% of that required to operate at maximum loading rate, *i.e.* the 'no load' consumption is 60%.

If we assume that the loading rate of such a furnace could be doubled to achieve optimum conditions, the fuel consumption/ton of steel would be reduced by approximately 37% and, of course, production would be increased by 100%.

The disposition of the load in the furnace is also of importance and it should be so arranged that:

(*a*) It receives maximum amount of radiation from the hot surfaces of the heating chamber.

(*b*) The hot gases are efficiently circulated around the heat-receiving surfaces.

Another factor that adversely affects efficiency is 'idling times.' This should be reduced to a minimum by careful planning of furnace utilization and by ensuring speedy charging and withdrawal of the load.

Maintenance

To ensure that heat-treatment furnaces continue to operate at maximum efficiency, adequate maintenance work must be regularly undertaken.

The most satisfactory way of keeping the plant in first-class condition is to have a planned maintenance routine to cover the whole of the plant.

Among the items that should receive periodic checks are the following:

1. BURNER EQUIPMENT Burners should be kept clean and in good repair. Nozzles should be in good condition and free from obstruction, such as carbon build-up. Oil burners need particular attention in this respect and oil preheat temperatures should be regularly checked to ensure that the oil is at the right viscosity at the burners.

Fuel and air supplies should be maintained at the correct pressures at the burners. Control valves should be easy to manipulate and in a good state of repair.

Burner positions and angle of firing should be periodically examined. Incorrect burner alignment often causes flame impingement on refractories and load, resulting in flame chilling and incomplete combustion.

2. FURNACE BRICKWORK Worn brickwork can be an important source of thermal loss. Furnace brickwork should be maintained in first-class order to reduce radiation losses and to prevent air infiltration or hot gas emission through cracks or holes. Hearth should be kept clean and scale build-up prevented.

(i) *Burner ports and quarls* These should be kept in good condition to prevent interference with combustion and flame shape.

(ii) *Dampers and flueways* Dampers should be free and in good working order and not subject to inleakage of air.

Flueways should be regularly inspected and any obstruction removed.

(iii) *Furnace doors* These can be a prolific source of heat loss and special attention should be given to the sealing of the doors.

(iv) *Sand seals* Sand seals on bogie-type furnaces should always be properly filled to prevent air infiltration or the outflow of hot gas, which may cause damage to bogie undercarriage.

Operational checks

Whenever possible periodic checks should be made to ascertain combustion efficiency. These should include analysis of the gases in the working chamber and flue offtakes to determine the CO_2 content and the measurement of draught conditions. Any loss of efficiency would be indicated by the readings obtained and appropriate steps could then be taken to effect an improvement.

Record keeping One of the best checks on the working of a furnace is to determine and record at regular intervals the amount of fuel used/unit of output. Comparison of any given week's performance with that of preceding weeks is a valuable check of furnace efficiency. Any falling off in performance should be investigated and the aim should be to continuously improve on past records.

Waste heat recovery

The chief loss of heat which occurs from a heat-treatment furnace is that which is carried away as sensible heat in the waste gases. The extent of this loss depends on the working temperature of the furnace and the composition of the waste gases.

By recovering and utilizing some of this waste heat a substantial saving in fuel costs can be achieved. The methods used for recovering this heat are:

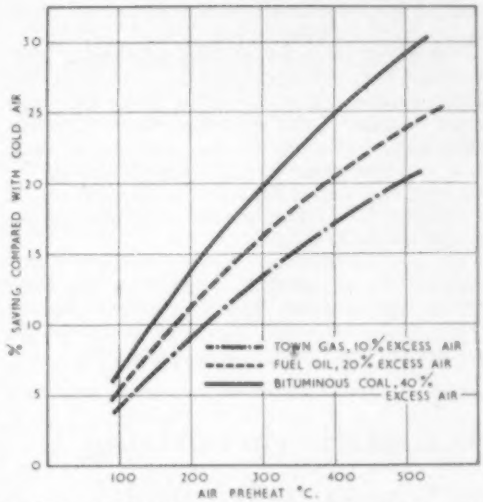
(*a*) By preheating the combustion air through heat exchanger.

(*b*) By preheating the load before it enters the working chamber. This is termed load recuperation.

(*c*) By using it for steam raising, water heating, space heating, etc.

Combustion air preheat The abstraction of heat from the waste gases and its transfer to the combustion air is carried out by a recuperator.

Recuperators used for this purpose are usually simple in design and units have been constructed to provide preheated air at a temperature in the order of 200°C. from an operating temperature of 800°C. This is equivalent to a fuel saving of approximately 10%.



4 *Approximate fuel savings due to air preheat. Waste-gas temperature* 800°C.

Fig. 4 shows the percentage of heat that is returned to the furnace by using various degrees of air preheat.

Load recuperation In this case waste heat is utilized for preheating the cold load before it enters the heating chamber. This is done by inserting the load in the first place into a preheating chamber, or by use of a continuous furnace. In the latter case the load travels in the opposite direction to the waste gases and thus a considerable quantity of heat is transferred to the incoming material and thermal efficiency may be as high as 60%. This compares with 20–40% efficiency in a batch-type furnace.

Application of waste heat for other purposes Providing scope exists, considerable fuel savings can be made by using waste heat for steam raising, space heating, drying, etc.

Before its application for these purposes, however, it is essential to know if the quantity of waste heat from furnace or furnaces will be sufficient to meet the demand and the times of its availability.

The capital costs involved in recovering waste heat and distributing it to its point of application must be fully considered. Generally, if capital expenditure is not recovered in three to four years by the fuel savings achieved, it is not considered to be an economic proposition.

Conclusions

From the foregoing notes it will be appreciated

that the achievement of optimum furnace efficiency is dependent on many factors.

The basic principles of economic furnace performance are good design with the incorporation to a maximum extent of insulating brickwork, maximum combustion and operating efficiency, instrumentation, regular maintenance, recovery of waste heat whenever possible, and optimum loading. It has been emphasized that one of the major causes of inefficiency is the failure to ensure maximum utilization of the furnace capacity.

By careful attention to the items mentioned, furnace efficiencies can often be greatly increased and fuel savings achieved. The extent of these savings varies considerably, but experience shows that on average the figure lies between 20 and 30%.

Automatic carburizing at Standard-Triumph

A MODERNIZATION SCHEME to provide fully automatic control of carburizing and carbo-nitriding furnaces has been completed by the Standard-Triumph organization at their Fletchamstead and Radford works, Coventry. The scheme uses the endothermic-gas technique.

Main shafts, gear wheels, pinions, differentials, cluster gears and similar parts require careful hardening if their dimensions and properties are not to suffer. Using the new scheme, the company finds that certain gear wheels are retaining their dimensions to some 0·004 in. accuracy and have a surface finish after nitriding that makes them suitable for assembly direct into vehicle gear boxes. Both factories incorporate precisely controlled quenching after treatment; at Fletchamstead the quenching is embodied in the furnaces and at Radford press-quenching is a separate operation.

Fletchamstead

There are four single-zone Wild-Barfield furnaces at Fletchamstead with carburizing and stabilizing time controlled by four sets of instruments on a large panel. A Honeywell electronic strip chart recorder-controller inter-operates with two process timers which reset themselves after completion of the cycle. Carburizing normally takes place at about 940°C. and carbo-nitriding at around 815°C. Each set of instrumentation includes a section housing manual controls for the ammonia, propane and air producing the endothermic gas. There are also Pyr-O-Vane instruments by Honeywell which indicate and cut off fuel flow under excess temperature conditions, similar instruments safeguarding the gas generator elsewhere.

The panel also includes Honeywell controllers for two 160°C. tempering furnaces. A separate recorder-controller keeps oil supply temperature constantly at 55°C. to within 1°C., and during quenching, a Burrell process timer on each furnace keeps the oil temperature steady.

Dewpoint control is provided by Foxboro-Yoxall circular chart controllers.

Radford 85 ft. panel

Automation of a different kind is provided on two G.W.B. three-zone carburizing furnaces at Radford, where an 85 ft. panel includes both automatic and push-button control. The automatic control for each furnace is provided by three Honeywell circular scale controllers, one per zone, and a permanent record is given on a multipoint strip chart recorder alongside. Zone temperatures are respectively in the region of 820, 840 and 920°C. A further two Honeywell recorders give tempering furnace temperatures and quench temperatures. Quenching take place on Gleason presses, the moment of quench being determined by Honeywell contact controllers which start the quenching cycle when the work-piece temperature falls to a given level, as detected by a Radiamatic radiation pyrometer.

Control of the endothermic gas temperature of 1,040°C. is obtained to a closeness of ± 2°C. by a controller from the same supplier. Dewpoint is controlled by Foxboro-Yoxall instruments as at the other factory.

Trade associations and public relations

'A function of a trade association which has grown in importance in recent years is that of public relations. This covers relations with the Government and the nationalized industries as well as the formation of public opinion. The standing and goodwill of an industry are of vital importance to all its constituent firms and the establishment of good public relations must, therefore, be a primary duty of a trade association.' This was said by Mr. Stanley F. Steward, C.B.E., M.I.PROD.E., director of the British Electrical and Allied Manufacturers Association, when presenting a paper on 'British Electrical Manufacture in the National Economy' to the British Electrical Power Convention, at Eastbourne recently.

The trade association provided an essential channel of contact, information and, most important from the industry's point of view, interpretation. At the same time the trade associations were of benefit to the Government itself firstly, as an informed and informal point of contact on industrial matters and, secondly, as a representative and informal channel of communication with industry. In fact, it was difficult to see how Government policy could be effectively transmitted in the business sphere under modern conditions without the service and help it got from trade associations.

Precipitation in low-carbon steel under cyclic loading

Doc. Ing. MIRKO KLESNIL and Doc. Dr. Ing. PREMYSL RYS

After briefly reviewing previous work in the field, the authors describe their investigation of the mechanical constants and the changes in the structure of the solid solution of carbon in alpha iron in the equilibrium and supersaturated states using two low-carbon steels. The original publication of this work was in 'Hutnické Listy', 1961 (8). *The authors are at Československá Akademie Ved, Laborator pro studium vlastností kovu, Brno, Czechoslovakia*

IN IRON-CARBON ALLOYS, carbon and nitrogen form an interstitial solid solution in the alpha iron. Since the solubility of both these elements falls with decreasing temperature, conditions are favourable for the formation of a supersaturated solid solution and its breakdown through precipitation. The presence of relatively small quantities of interstitial elements in the solid solution of alpha iron has a considerable influence on the mechanical properties of the steel during static loading; through their presence it is possible to explain, for instance, the marked yield point,[1, 2] blue brittleness, and various types of ageing as a manifestation of simple and combined hardening.[3, 4] The properties indicated, whose essence lies in the manner of distribution of the interstitial elements and in their interaction with the dislocations, are well known and do not require more detailed explanation.

During oscillating loading, Fe-Cr alloys display certain characteristic features, which can also be ascribed to the action of the atoms of interstitial elements which are present. On a Wöhler fatigue curve, alloys of this type have a characteristic discontinuity, which determines the fatigue limit, and is manifested after a number of cycles of 10^6–10^7. Pure metals and substitutional solid solutions have, on the contrary, a continuous form of Wöhler curve, and the stress amplitude, at which breakdown of the cohesion takes place, falls steadily with the increase in the number of load cycles.

For evidence that the anomaly on the Wöhler curve of Fe-C alloys is brought about by the presence of atoms of carbon and nitrogen, Lipsitt and Horne[5] carried out a series of experiments with low-carbon steel with a yield point of 26·3 kp./mm.^{2}, and a fatigue limit in tension-compression of 19·7 kp./mm.^{2} Part of the specimens were annealed at 940°C. for a period of 100 hours in an atmosphere of moist hydrogen. After this heat treatment, the carbon content fell to 0·003–0·005% and the nitrogen content to 0·00018%. The yield point dropped to 8·5 kp./mm.^{2} and the fatigue limit to 12·6 kp./mm.^{2} At the same time the marked discontinuity on the Wöhler curve vanished, and to the extent that it remained very slightly visible, was displaced towards the range of a higher number of load cycles.

It may be judged that the fatigue limit of Fe-C alloys occupies a similar place in the sphere of alternating loads as the yield point during static loading, and is brought about by the diffusion of interstitial atoms and their interaction with the dislocations. This opinion is also confirmed by further examples.

One of the marked factors manifested in Fe-C alloys consists in the raising of the fatigue limit by stressing below the fatigue limit (understressing, coaxing). The results of systematic investigation of this phenomenon carried out by Sinclair,[6] who used various types of alloys (bronze, aluminium alloys, low-carbon steels), showed that the effect described is completely missing in bronze and aluminium alloys; it is manifested only in steel, and is closely connected with the diffusion of interstitial atoms into the lattice defects.

In the same way, the action of higher temperatures on the fatigue characteristics of steel also shows the influence of the diffusion of interstitial elements. Moore and Alleman[7] found in steel with a 0·17% C content, that the fatigue limit increased from 21·1 kp./mm.^{2} to 27·4 kp./mm.^{2} during

experiments at a temperature of 290°C. Levy and Sinclair[8] indicated the substantial increase in the fatigue limit, which attained a maximum around a temperature of 230°C. If the interstitial atoms were removed by long-term annealing in an atmosphere of moist hydrogen, the effect of increasing the fatigue limit in the range of higher temperatures would vanish. The authors considered that the increase in the fatigue limit is brought about by the effect of hardening, and that the atoms of interstitial elements are capable at an elevated diffusion rate of following the movement of the dislocations during a single load cycle, and thus of retarding the compass of the plastic deformation.

The effect of cyclic loading on diffusion and the breakdown of a supersaturated solution of iron through precipitation is shown in many papers. Schenck and Schmidtmann[9] showed that carburization of steel at 900°C. took place much more rapidly, if the specimens were simultaneously subjected to cyclic loading. The greater was the stress amplitude used, the more rapidly the carbon diffusion progressed.

Hempel and Houdremont[10] discovered metallographically after cyclic loading of specimens of low-carbon steel (0·02% C), which had been plastically deformed by uniaxial tensile loading before testing, that there was precipitation of carbides in the slip planes formed by the action of the static deformation. After electrochemical separation of the precipitates, it was confirmed by X-ray analysis that it was a matter of particles of Fe_3C. Microscopic observation showed, that precipitation of cementite does not take place during loading of the specimens below the fatigue limit and at high stress amplitudes leading to breakdown of the cohesion after a small number of cycles. The authors considered that, in the first instance, the diffusion of carbon which is proportional to the stress amplitude is excessively small, and that, in the second instance, the specimens fractured earlier than true precipitation of the cementite phase took place.

A quantitative analysis of the phase transformation in hardened steel with a 0·88% C content, symmetrically loaded with an oscillating bending stress with a frequency of 417 cycles/min. was carried out by Lukáš.[11] By X-ray analysis he showed the fall in the carbon content of the martensite, the formation of epsilon carbides and the drop in the content of residual austenite. The changes were found above and below the fatigue limit of 64 kp./mm.^{2}; with increasing stress amplitude they became more pronounced. At the same time the temperature of the surface of the specimen was measured in the area under the maximum load. It was shown that the specimen heated up only slightly and at a stress amplitude of $\sigma_a = 65 \cdot 8$ kp./mm.^{2} attained a temperature of 32°C. But the author showed that after heating at a temperature of 37°C. for a period comparable with the time of loading no measurable changes take place.

Klesnil,[12] during a study of the fatigue process in steel (0·35% C), quenched and tempered at 600°C. for a time of 1 hour, found by means of X-rays a fall in the lattice constant during loading above the fatigue limit. With decreasing stress amplitude this change becomes less marked and vanishes at the fatigue limit. Since internal stress was not found either in the initial state or during loading, the author connects this phenomenon with diffusion of carbon into the cyclically deformed zones of ferrite, which are etched with less intensity and have a different surface relief from that of the ferrite background material.

The results of these and other studies[13] confirm that in Fe-C alloys during cyclic loading there is a substantial increase in the extent of the diffusion of the interstitial atoms. The specific fatigue characteristics of these alloys show that diffusion of the interstitial atoms is the process which controls the formation and development of the fatigue breakdowns in cohesion of the ferrite background material.

Materials and method of testing

For the investigation of the mechanical constants and the changes in the structure of the solid solution of carbon in alpha iron in the equilibrium and supersaturated states two types of steel were chosen: low-carbon steel with a 0·05% C content and a 0·0042% N content, and steel to specification ČSN 12010 (0·09% C).

The low-carbon steel with a 0·05% C content was first heated at a temperature of 1,000°C. for 1 hour with subsequent gradual cooling in the furnace for a period of 24 hours. By this means, almost the equilibrium state was reached and a suitable grain size of about 0·1 mm. From the material prepared in this way specimens were machined (fig. 1). Some of the specimens were preserved in the original state of heat treatment while others were heated at a temperature of 700°C. for 1 hour and then rapidly quenched in water at a temperature of 20°C. All the specimens were ground and electrolytically polished before testing. By polishing away a layer about 50μ thick, the plastically deformed strip formed during machining and grinding was removed. The specimens prepared in this way were symmetrically loaded by oscillating flexure on a machine of our own design with a frequency of 400 c./min. Quenching of each specimen from a temperature of 700°C. in water at a temperature of 20°C. was carried out very shortly before testing mechanically. The Wöhler curves constructed from the results of

measurements of specimens in the original state of heat treatment and after quenching from a temperature of 700°C. are shown in fig. 2.

From steel ČSN 12010 in the normalized state (grain size about 0·02 mm.) specimens were machined (fig. 3) and treated in the same way as the specimens shown in fig. 1. Loading by symmetrical oscillating flexure was carried out on a Schenck-WEBI machine with a frequency of 1,470 c./min. The Wöhler fatigue curves for steel in the normalized state and for steel quenched from a temperature of 700°C. are shown in fig. 4.

Changes in the structure brought about by the action of the cyclic loading and supplementary heating were observed metallographically with a Zeiss-Neophot optical microscope and a Tesla BS-242 table-type electron microscope. For observation in the electron microscope two-stage, collodion-carbon replicas, shadowed with gold and palladium, were used.

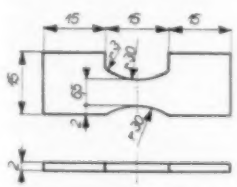
For supplementary hardening after loading the specimens were heated inside a thermostatically-controlled heating element, and the temperature established was maintained within the limits of ±0·05°C.

The hardness was measured by the Vickers method, the macro-hardness by loading at 10 kp. and the micro-hardness by loading at 100 p. The resultant hardness values were determined as the arithmetic mean of ten measurements. For this arithmetic mean the mean quadratic error was determined by calculation; it varied for measurement of the macro-hardness within the limits of ±(0·5 to 2) Vickers hardness units, and for measurement of the micro-hardness within the limits of ±(1 to 3·5) Vickers hardness units.

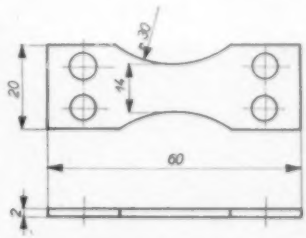
On the specimens of the microstructures the section marked corresponds to 1μ in reality.

Results of the experiments

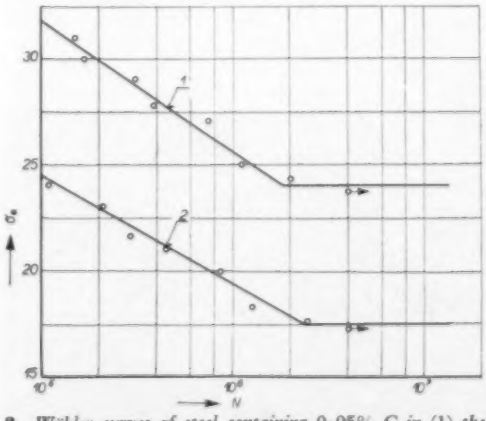
Precipitation of the carbide phase from the supersaturated, solid solution of alpha iron in steel containing 0·5% C has already been described in an earlier paper.[4] The time sequence of the hardness of the quenched specimens, subjected to the action of temperatures of 23, 97 and 128°C., has a sequence characteristic of a precipitation process (fig. 5). The originally homogeneous purely ferritic structure gradually changes. The ascending part of the hardness curves corresponds to the evolution of an inhomogeneous solid solution which is manifested by wrinkling of the surface of the grains of ferrite (fig. 6*a*). Marked precipitation (fig. 6*b*) can be shown only on the descending sections of the hardness curves. Through cold plastic deformation



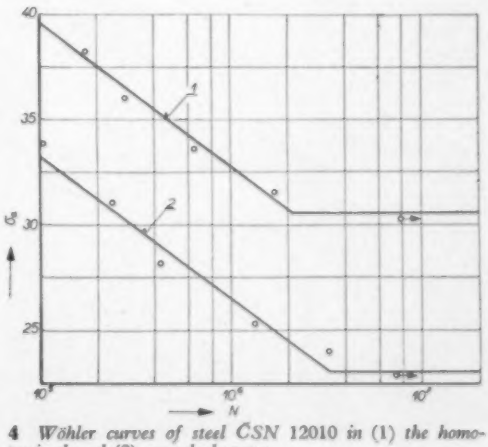
1 *Shape of a test specimen*



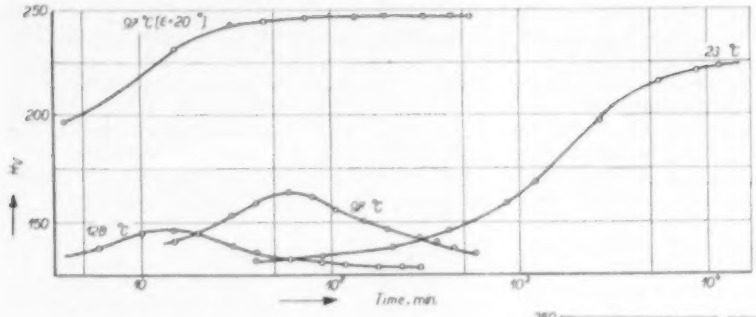
3 *Shape of a test specimen*



2 *Wöhler curves of steel containing 0·05% C in (1) the original and (2) the quenched states*



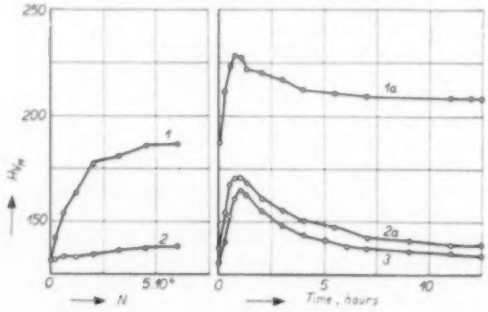
4 *Wöhler curves of steel ČSN 12010 in (1) the homogenized and (2) quenched states*



5 *Time sequence of the hardness during hardening of steel containing 0·05% C at various temperatures*

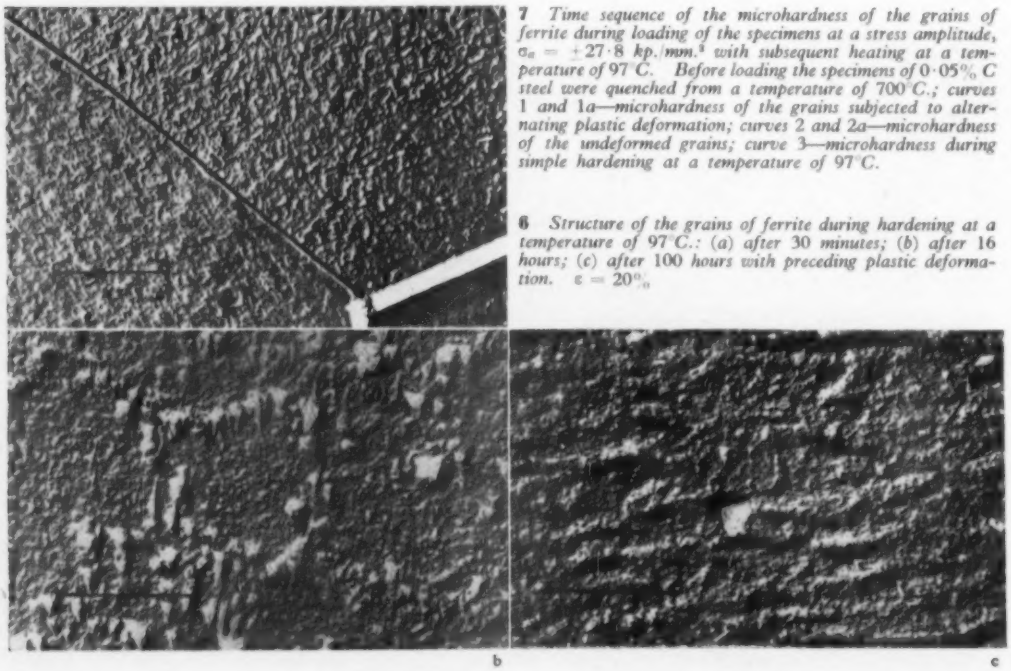
(ε = 20%) there is a growth in the nucleation capacity of the matrix, and hardening proceeds more rapidly and with greater intensity at a temperature of 97°C. than without preceding mechanical working (fig. 5); after reaching the maximum value the hardness decreases only slightly. In addition stabilization of the hardness can be found to correspond to stabilization of the structure; even after a longer time of heating no marked precipitation takes place but only wrinkling of the surface (fig. 6*c*).

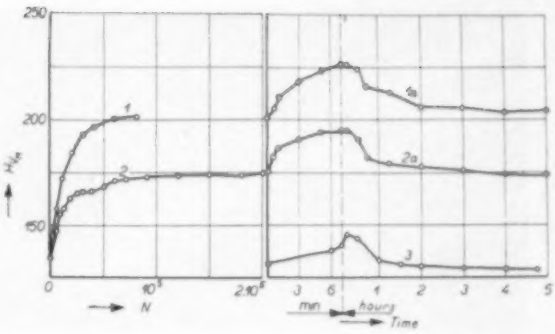
During cyclic loading, after a relatively short



7 *Time sequence of the microhardness of the grains of ferrite during loading of the specimens at a stress amplitude, $\sigma_a = \pm 27{\cdot}8$ kp./mm.² with subsequent heating at a temperature of 97 C. Before loading the specimens of 0·05% C steel were quenched from a temperature of 700 C.; curves 1 and 1a—microhardness of the grains subjected to alternating plastic deformation; curves 2 and 2a—microhardness of the undeformed grains; curve 3—microhardness during simple hardening at a temperature of 97 C.*

6 *Structure of the grains of ferrite during hardening at a temperature of 97 C.: (a) after 30 minutes; (b) after 16 hours; (c) after 100 hours with preceding plastic deformation. ε = 20%*



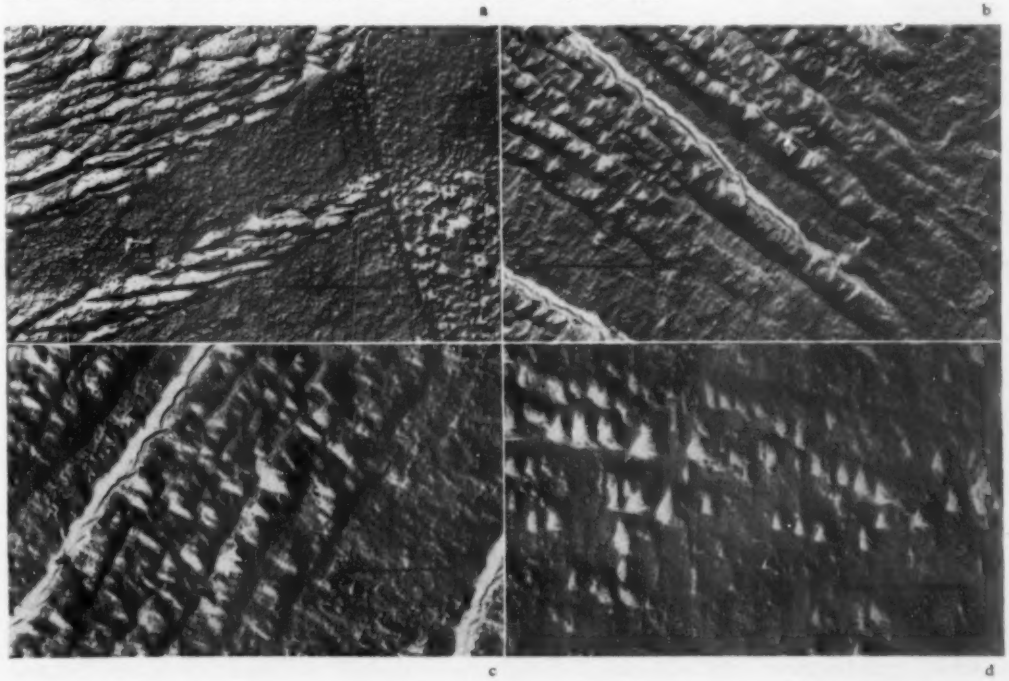


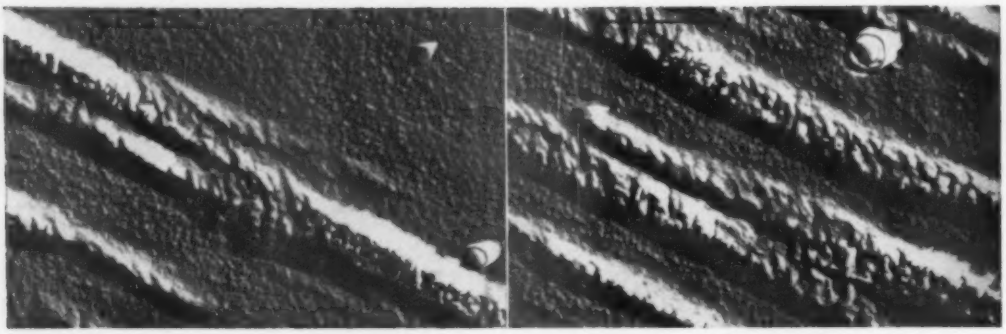
8 *Time sequence of the microhardness of the grains of ferrite during cyclic loading with subsequent heating at a temperature of 128°C. The specimens of steel containing 0·05% C were quenched from a temperature of 700°C. before loading; curves 1 and 1a microhardness of the grains plastically deformed at an alternating stress amplitude, $\sigma_a = \pm 30{\cdot}0$ kp./mm.²; curves 2 and 2a microhardness of the grains plastically deformed at an alternating stress amplitude, $\sigma_a = \pm 27.8$ kp./mm.²; curve 3 microhardness during simple hardening at a temperature of 128°C.*

time a considerable increase takes place in the hardness of the grains of ferrite subjected to alternating plastic deformation. The micro-hardness sequence of the deformed grains of steel containing 0·05% C quenched from a temperature of 700°C. in relation to the number of cycles at a stress amplitude of $\sigma_a = \pm 27{\cdot}8$ kp./mm.² is shown in fig. 7 (curve 1) and in fig. 8 (curve 2). In the graph in fig. 7 is simultaneously plotted the change in the hardness of the unloaded area of the specimen (curve 2); its time sequence corresponds to hardening at a temperature of 23°C. A similar increase in hardness was found also at a stress amplitude of $\sigma_a = \pm 30{\cdot}0$ kp./mm.² (curve 1, fig. 8). From the results it follows that the greater the stress amplitude, the more the hardness increases.

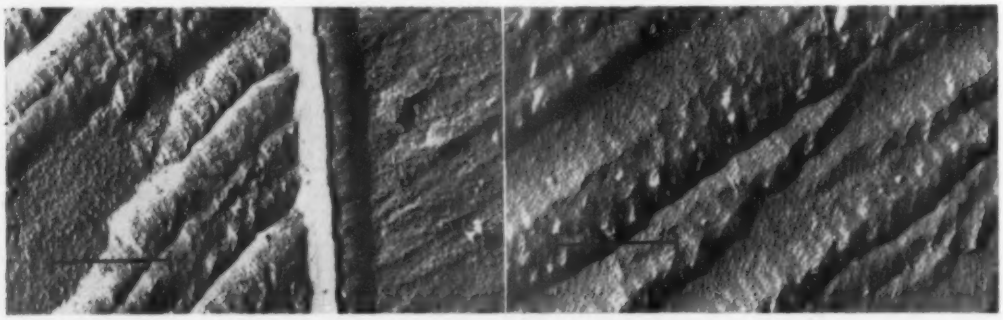
Simultaneously with measurement of the hard-

9 *Structure of the slip bands in the grains of ferrite (0·05% C steel); the specimens were quenched from a temperature of 700°C. before loading at $\sigma_a = \pm 25$ kp./mm.², $N = 8 \times 10^5$: (a) relief of a slip band; (b) and (c) after etching the specimen; (d) after polishing away a layer of about 1 micron and after etching*





10 *Structure of the slip bands in the grains of ferrite (0·05% C steel); the specimens were quenched from a temperature of 700°C. before loading at $\sigma_a = \pm 27{\cdot}8$ kp./mm.², $N = 2 \times 10^6$: (a) after etching the specimen; (b) after polishing away a layer of about 1 micron electrolytically and etching*

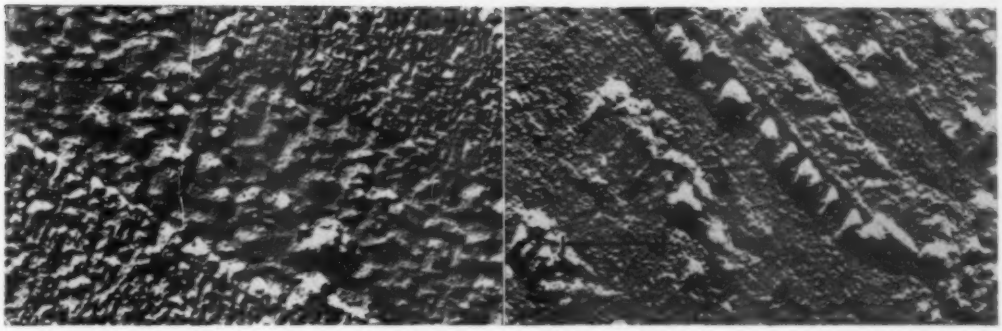


11 *Structure of the slip bands in the grains of ferrite (0·05% C steel); the specimens were quenched from a temperature of 700°C. before loading at $\sigma_a = \pm 30$ kp./mm.²: (a) after etching the specimen; (b) after polishing away a layer of about 1 micron electrolytically and etching*

ness, the changes in structure were investigated with the electron microscope. The relief which forms through the action of the alternating plastic deformation on the polished surface of the grains of alpha iron supersaturated with carbon, during loading at a stress amplitude of $\sigma_a = \pm 25$ kp./mm.² which exceeds the fatigue limit by 4·17% (fig. 9*a*), differs in no way from the relief which is manifested in the grains of ferrite with a carbon concentration approximating to the equilibrium state.[14] From the microstructure, it is apparent that in the slip band the oscillating deformation forms a very reticulated relief, consisting of a synthesis of very irregular elevations and depressions.

After etching away a thin surface layer of the specimen in 2% Nital (etching time 30 sec.), the slip bands remain visible and project slightly above the level of the surface of the matrix of ferrite (figs. 9*b* and 9*c*). In the actual structure of these deformed bands platelet formations with a regular orientation are apparent, with thickness of about 500 Å. After polishing away a thin layer of about 1μ electrolytically and after etching, the slip bands, called permanent slip bands, are again manifested (fig. 9*d*), and the character of their relief remains preserved. On comparing figs. 9*b*, 9*c* and 9*d* with 6*b* it is possible to identify the formations described as carbide precipitates. It is necessary to emphasize that these shapes are not observed in the structure of the permanent slip bands after cyclic loading of the specimens whose heat treatment was chosen in such a way that the C content of the ferrite approaches the equilibrium state at normal temperatures.[14]

In essence the same data were obtained at a stress amplitude of $\sigma_a = \pm 27{\cdot}8$ kp./mm.² exceeding the fatigue limit by 15·8%. The micro-hardness sequence of the ferrite grains of the specimen which was used for the metallographic research is shown in fig. 8 (curve 2). A micrograph of the structure of the ferritic grain of the specimen which was etched after loading is shown in fig. 10*a*.



12 *Structure of the slip bands in the grains of ferrite of 0·05% C steel; the specimens were quenched from a temperature of 700°C. after cyclic loading at* $\sigma_a = \pm 30$ *kp./mm.², N* $= 8 \times 10^4$, *and heated at a temperature of 128°C. for a period of 9 hours.*

13 *Structure of the slip bands in the grains of ferrite of 0·05% C steel; the specimens were quenched from a temperature of 700°C. after cyclic loading at* $\sigma_a = \pm 27{\cdot}8$ *kp./mm.², N* $= 1 \times 10^5$, *and heated at a temperature of 97°C. for a period of 15 hours.*

In the slip bands, rising above the level of the metallic background material, less readily etched formations in the shape of platelets are again to be observed. After polishing away a surface layer of about 1μ and after etching, the appearance of the band was unchanged (fig. 10*b*). The ferrite matrix is only moderately wrinkled, and in it no marked precipitates are evident.

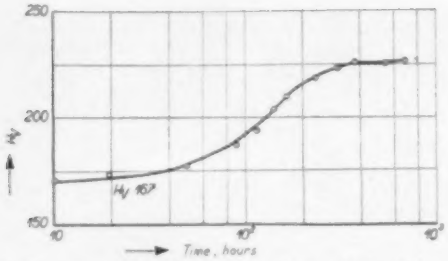
On employing a stress amplitude of $\sigma_a = \pm 30{\cdot}0$ kp./mm.², exceeding the fatigue limit by 25%, for which the corresponding hardness sequence of the deformed grains of the test specimen is designated as curve 1 in fig. 8, the slip bands become more numerous and often whole grains are covered by the relief of the plastic deformation. The appearance of the deformed areas, both after etching (fig. 11*a*), and also after polishing away a surface layer of about 1μ and etching (fig. 11*b*), is similar to that at lower stress amplitudes except that the platelet formations are finer. Similarly, also, in this instance, there is relatively little wrinkling of the metallic background material, and it is impossible to identify within it any carbide precipitates.

The effect of higher temperatures on the hardness and microstructure of the deformed grains of ferrite was investigated in a further series of tests. The specimens were first of all subjected to cyclic deformation and then hardened at temperatures of 97 and 128°C.

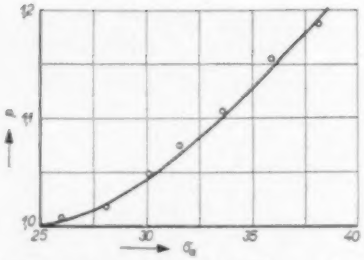
Fig. 8, curves 1*a* and 2*a*, shows graphically the hardness sequence of the specimens which were heated after loading at a temperature of 128°C. For comparison, in the same figure is shown the hardness sequence of a specimen after simple hardening at a temperature of 128°C. (curve 3). From the diagram, it is evident that by hardening after cyclic deformation higher hardness values are attained than by simple hardening at a temperature of 128°C. Curves 1*a* and 2*a* show that in the initial stage of heating the hardness first of all increases rapidly, but falls gradually after attaining a maximum. The curves have a similar course to that of curve 3 with the difference that the hardness values are higher and the time required to attain the maximum is shorter.

The structure of the ferrite of the specimen which was loaded at a stress amplitude of $\sigma_a = \pm 30$ kp./mm.² and heated for a period of 9 hours at a temperature of 128°C. (curves 1, 1*a* in fig. 8) and from which a surface layer of 2μ was polished away, is shown after etching in fig. 12. In the micrograph is to be seen a ' permanent slip band ' which contains correspondingly oriented formations. The matrix of ferrite is strongly wrinkled, which can scarcely, however, qualify as a phenomenon of the precipitation of an incoherent phase.

A similar effect was obtained by heating at a temperature of 97°C. after alternating loading with a stress amplitude of $\sigma_a = \pm 27{\cdot}8$ kp./mm.² (fig. 7, curves 1 and 1*a*). For comparison is shown the hardness sequence of a specimen which was quenched after direct hardening at a temperature of 97°C. (curve 3); the increased hardness values in the unloaded area of the cyclically loaded specimen, found over the whole of the hardening sequence (curve 2*a*), can be explained by the effect of combined hardening.[4] The structure of the ferrite grain of the specimen prepared in this way, after polishing away a surface layer of 2μ and after etching, is shown in fig. 13. In the micrograph are visible ' permanent slip bands ' containing correspondingly oriented formations which are etched with less intensity. Also, in this instance, in the



14 *Time sequence of the hardness during the hardening of steel ČSN 12010 at a temperature of 23°C.*



15 *Change in the ratio of the hardness values of the deformed and undeformed areas of specimens of steel ČSN 12010 in relation to the stress amplitude*

ferrite background material, it is impossible to discern any carbide precipitates outside the deformation band.

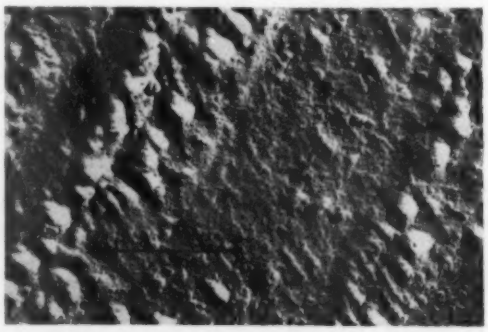
For further support for our opinion on precipitation through the action of cyclic deformation, research was also carried out on steel ČSN 12010. The hardness time plot for hardening at a temperature of 23°C. after quenching from a temperature of 700°C. is shown in fig. 14.

On all the experimental specimens used for the construction of the Wöhler curve the macrohardness was measured after their fracture and, in fact, in both the loaded and the unloaded areas. The ratio between these hardness values as a function of the stress amplitude is shown in fig. 15. From the graph it follows that with falling stress amplitude the hardness values in the stressed and unstressed areas approach each other; this implies that the intensity of the precipitation hardening is diminished with decreasing stress amplitude. For investigation of the structure of the slip bands we used a specimen loaded at a stress amplitude of $\sigma_a = \pm 31{\cdot}5$ kp./mm.², *i.e.* 3·28% above the fatigue limit. After polishing away a surface layer of 1μ and after etching (fig. 16), the same picture of the relief of the slip bands was obtained as for the steel with a 0·05% C content, as is proved by comparison between figs. 9*b*, 9*c* and 9*d* on the one hand and fig. 16 on the other.

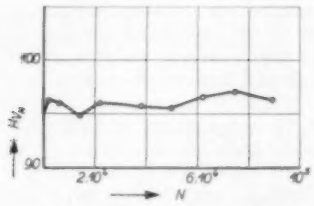
Analysis of the results

In an earlier work, carried out on steel containing 0·05% C, an interpretation was given of the course of hardening which is the result of the breakdown of a supersaturated solid solution of alpha iron through precipitation. At the low nitrogen content of this steel, by means of thermodynamic analysis, the decisive role of carbon on hardening was shown. The course of precipitation is influenced by the rate of diffusion and the nucleation powers of the matrix. The hardness time sequence after hardening at various temperatures is different, and it may be explained by the effect of the different rate of diffusion and the changing size of the critical dimension of the nucleus (fig. 5). The actual precipitation was shown to correspond to the descending sections of the curve (fig. 6*b*), and the pre-precipitation states of the inhomogeneous solid solution to correspond to the ascending part of the curve (fig. 6*a*). The increase in the nucleation capacity of the matrix after mechanical working by static loading leads to a greater increase in hardness (fig. 5) and to stabilization of the structure (fig. 6*c*) and of the hardness (fig. 5).[4]

The effect of cyclic loading on the breakdown of a supersaturated solid solution of alpha iron through precipitation was studied on the same steel containing 0·05% C. The experiments showed the rapid increase in hardness of the deformed grains. The increase in hardness cannot be attributed to the action of hardening occurring during plastic deformation through fragmentation of the grains. Strain hardening of this sort is manifested in steel only at stress amplitudes exceeding the cohesive strength,[14] whereas loading in the



16 *Structure of the slip bands in the grains of ferrite of steel ČSN 12010. The specimens were quenched from a temperature of 700°C. before loading at* $\sigma_a = \pm 31{\cdot}5$ *kp./mm.²,* $N = 1{\cdot}2 \times 10^6$



17 *Sequence of the microhardness of the cyclically deformed grains of the ferrite of heated specimens of 0·05% C steel* ($\sigma_a = 23 \cdot 0$ *kp./mm.²*)

range of the Wöhler curve employed ($N > 10^5$) proceeds in the phenomenologically elastic range.

For comparison, measurement was made of the hardness sequence as a function of the number of cycles on a specimen heated at 1,000°C. for 1 hour with gradual cooling in the furnace. The stress amplitude used was $\sigma_a = \pm 23 \cdot 0$ kp./mm.², at which rupture takes place after approximately the same number of cycles as for the specimen quenched from a temperature of 700°C. if we choose a stress amplitude of $\sigma_a = \pm 30 \cdot 0$ kp./mm.² (fig. 2). The micro-hardness curve of the deformed grains of ferrite is shown as a graph in fig. 17. The measured changes in hardness are very inconsiderable and are within the extent of the mean quadratic error of measurement.

The metallographic analysis showed that in the permanent slip bands during cyclic loading, marked and rapid precipitation takes place at normal temperatures; this phenomenon may be considered to be the main cause of the increase in hardness of the deformed grains. The accelerated breakdown of the supersaturated solid solution of alpha iron may be explained by the increased rate of diffusion in the slip bands under the action of the alternating loads. It would be simplest to suggest that the slip bands have a higher temperature than the undeformed matrix. Since, however, the total of the surface areas bounding the slip bands is greater than the surface area of the specimen, its temperature must be comparable with that of the deformed slip bands.

In order to exclude the possibility that at low loading frequencies (400 c./min.), accelerated precipitation takes place through heating up of the specimen, we measured the temperature with a thermocouple at a stress amplitude of $\sigma_a = \pm 30 \cdot 0$ kp./mm.² The results of this measurement did not show any change in temperature. Therefore it is impossible to assume a substantial rise in the temperature of the deformed bands, even though it is necessary to admit a short-term rise in temperatures on the submicroscopic scale. The main source of heat generation may be considered to be the moving dislocations. In this sense a series of calculations have been carried out on the basis of mechanically-worked models.[15, 16] A localized increase in temperature lasts for the time of movement of a dislocation and is dependent on its velocity; at the proposed rates the time of movement is less than a thousandth of a second. Thompson and Wadsworth[12] consider that the increase in temperature in the submicroscopic volume with consideration of the times of action is negligible for diffusion.

It is necessary to take into consideration that diffusion can be promoted by the dislocations and vacancies which form during cyclic deformation. It has been shown that diffusion along the dislocations proceeds much more rapidly than in the metallic background material where the cohesion is unbroken.[17] Forsyth[18] used specimens produced from Al-Zn-Mg-Cu alloy for cyclic loading; the specimens were metallized with a thin layer of aluminium. It was found that during heating after alternating loading, the atoms of the dissolved elements are diffused at the grain boundaries and thence into the grains along the slip bands. Here, therefore, it is probable that, in our instance, the accelerated diffusion is brought about by the dislocations and vacancies occurring during cyclic loading, rather than through the increased temperature of the slip bands.

The precipitation in the permanent slip bands which was shown by electron microscopy is dependent on the conditions of cyclic loading; at a higher stress amplitude the increase in hardness is greater, the precipitates are finer, and their number is greater. The increase in the number of precipitates and their smaller size may be explained by the greater nucleation capacity of the matrix; on using higher amplitudes a greater number of lattice defects are formed, which act as the nuclei for the precipitation of a greater number of particles. The nuclei of the precipitates are mutually equipollent, and therefore stabilization of the structure and properties is manifested in the same way as occurs after static mechanical working or after combined hardening.[4]

As opposed to simple hardening, the basic difference lies in the fact that pronounced precipitates may be found not only in the range of the maximum of the hardness time sequence but also within the range of its ascending section. This phenomenon may be explained by the substantially greater concentration of precipitates than during simple hardening. The matrix which is unaffected by the plastic deformation is devoid of precipitates, and has only a wrinkled surface through the action of the gradually increasing inhomogeneity of the solid solution, corresponding to the sequence of simple hardening at the experimental temperature of the specimen (figs. 9*b*, *c*, *d* and 10*a* and *b*).

During the heating of specimens which have been hardened by cyclic loading there is a further increase in hardness; this increase in hardness is only very slightly greater than the increase in hardness of a specimen after heating at the same temperature immediately after quenching (see fig. 7, curves 1*a* and 3). It may therefore be deemed that this increase in hardness is the result of the precipitation processes in the undeformed matrix; the greater increase in hardness during heating after loading may be explained by the action of combined hardening,[4] evidence of which is provided by the course of time-hardness plots (curves 3 and 2*a* in fig. 7). Whereas during the heating of the supersaturated solid solution of alpha iron at temperatures of 97 and 128°C. after a given time precipitates are apparent in the matrix (fig. 6*b*), the structure of the undeformed matrix of the cyclically loaded specimens heated at the same temperatures and for the same time are devoid of marked precipitates (figs. 12 and 13). This fact and the sequence of the hardness curves with a relatively moderate fall in hardness over longer heating periods confirm the action of the combined hardening.

Comparison of the course of precipitation after mechanical working by a static force and during cyclic loading points to the basic differences in the character of the two methods of plastic deformation. After mechanical working with a static force, with the rise in temperature there is an increase in hardness (fig. 5) without the formation of marked precipitates (fig. 6*c*), and stabilization of the hardness and of the structure is manifested. It has been shown[4] that, in essence, it is a matter of a precipitation process similar to simple hardening, with the distinction, that by mechanical working with a static force, there is development of further lattice defects favourable to the formation of nuclei of the precipitating phase. After cyclic loading, in the slip bands numerous precipitates are apparent despite the fact that loading has taken place at normal temperatures.

The formation of precipitates under the conditions investigated may be explained by the fundamental change in the character of the matrix. The permanent slip bands in which precipitation takes place represent areas of breakdown in cohesion of the metallic background material, containing a smaller number of dislocations and a greater number of vacancies, which form through the interaction of the dislocations during the oscillating movements. The nucleation capacity of these areas is greater than the nucleation capacity of the matrix after deformation by a static force, and the greater number of vacancies permits substantially more rapid diffusion. In the permanent slip bands, therefore, conditions are favourable for precipitation to proceed even at normal temperatures under the action of the alternating plastic deformation, on a scale which is only possible at higher temperatures in the area of the matrix in which no cohesion breakdown has occurred. Therefore the results of the experiments confirm that the processes taking place in the internal structure of metals during cyclic and static loading are qualitatively different, and at the same time arouse doubts about the theories of Orowan, Afanas'ev and Mott,[19, 20, 21] who place on the same level the formation of cohesion breakdowns during alternating and static loading.

In essence the same data result also from research conducted on steel ČSN 12010. Measurement of the hardness in the loaded and unloaded areas of specimens at various stress amplitudes once more show that the plastically deformed zones of the ferrite primarily participate in the precipitation hardening. Morphologically the appearance of the permanent slip bands is the same as in coarse-grain steel with a 0·05% C content.

The marked effect of the carbon content in the lattice of the alpha iron on the sequence of the Wöhler curves is apparent from figs. 2 and 4; the specimens loaded immediately after quenching from a temperature of 700°C. have a fatigue limit which is higher by 37·1% (steel containing 0·05% C) and by 32·5% (steel ČSN 12010). The higher fatigue limit after quenching for both types of steel may be explained, not only by the higher yield point, but also by the intensive precipitation in the slip bands. The precipitates forming harden these bands, block their development, and restrict the possibility of the growth of submicroscopic cracks in the slip bands. The result of these processes is a considerable increase in the fatigue limit by comparison with the state after heating, when in the deformed areas of the ferritic matrix there is no excess of interstitial atoms permitting marked precipitation.

Conclusions

During cyclic loading of a supersaturated solid solution of alpha iron at a low-frequency precipitation breakdown takes place in the slip bands through the formation of the carbide phase even without raising the temperature of the specimen. The result of the precipitation is a marked increase in the fatigue limit by comparison with the approximately equilibrium state after heating of the steel.

By comparison with the precipitation of carbides during heating at temperatures of 97 and 128°C., carbides are formed on the rising section of the hardness curve, and the hardness asymptotically approaches the limiting value. With the greatest probability the increase in hardness is brought

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Stress-relieving at Hunterston

Use of radiant heat on reactor pressure vessel

SUCCESSFUL COMPLETION of the stress-relieving of the first 70-ft. dia. reactor pressure vessel at Hunterston Nuclear Generating Station, Ayrshire, Scotland, is reported by the General Electric Co. Ltd. The station is being built for the South of Scotland Electricity Board by the G.E.C. and Simon-Carves Atomic Energy Group. The construction of the pressure vessels was sub-contracted out to the Motherwell Bridge and Engineering Co. Ltd., who were also responsible for the stress-relieving operation. About 1,800 tons of steel, situated at a mean height of 85 ft. above ground level, was heated to a temperature of 550°C., soaked for 12 h. and then allowed to cool slowly. A high degree of control was essential to prevent the temperature difference between any two points in the vessel exceeding a specified maximum.

Installed inside the pressure vessel and undergoing stress-relieving at the same time were the inner heat shield, the core-support grid, and the main gas seal between the walls of the inner heat shield and the pressure vessel. Certain portions of the hot and cold gas ducting and the nozzles for the charge/discharge and control-rod standpipes which penetrate the pressure shell were also included. The steel restraint beams for the graphite core were suspended from the inner-shell nozzles, and other items treated at the same time were laid on top of the grid cover plate.

Design requirements

The electric heating system used was proposed and designed by the Industrial Advisory Service of the South of Scotland Electricity Board, who acted as consultants for the heating scheme to the Motherwell Bridge and Engineering Co. Ltd. throughout the job.

When designing the heating system for this complex structure certain features of the type of heater to be used, the method of heater suspension and the insulation of the heating system were considered desirable.

To achieve uniform heating, radiant heating was to be adopted. The heaters needed to be arranged in zones with external means of varying the heat output of the heater groups in each zone. In order to obtain the best possible heat transfer from the heaters to the fabricated structure, the heaters should not be surrounded by insulation or sheaths. It was decided to employ heaters in the form of alloy strips.

Good electrical insulation required the heater strips to be widely spaced from earth and from each other to allow for the considerable expansion which would take place at the high temperatures involved.

The material used for the heater strip needed to have a high resistivity, so that a robust arrangement could be employed, and be sufficiently ductile for ease of forming. A low temperature coefficient of resistance and good resistance to progressive oxidation when hot were also necessary. Since bare conductors would be used to achieve maximum radiation, separate insulators became necessary.

General outline of scheme

The pressure vessel and included components were heated by a series of freely radiating Brightray strips supported by wire links and ceramic insulators. Some strips were mounted circumferentially between the spherical pressure vessel and the cylindrical inner heat shield, while others on the top and bottom crowns followed approximately the curvature of the vessel.

With the system of heater suspension employed, a curtain-like structure of heater elements was built up in the space between the inner heat shield and the pressure vessel.

Brightray heater strips were also placed underneath the grid to ensure that this would be adequately heated. Enclosed tubular-type heaters were employed for each of the gas ducts.

The method of suspension adopted was highly flexible and permitted the switching off of one heater without fear of damaging the suspension of neighbouring heaters.

It was considered necessary to divide the fabricated structure into 40 separate heating zones. By choosing suitably dimensioned heating strip it was possible to use 100-ft. lengths connected directly across the 240-V. mains. This length, half the circumference of the spherical pressure vessel, enabled the supply to be brought in at one side of the vessel and the neutral connection to be taken out of the other side.

Heaters and supports

Except for the ducts, all heaters were made of Brightray strip. Inside each zone the heater strips were connected in groups, each group being supplied from an externally-mounted auto-transformer fitted with voltage ratio adjustment. This allowed a measure of control to be exercised over individual heating groups.

Each duct heater was 8 in. dia. and 6 ft. long, with a rating of 24 kW. at 240 V., and of stainless steel construction. Two heating units were used in each hot gas duct, and one heating unit was employed in each of the shorter cold gas ducts. They were supplied by Duncan Low Ltd., Glasgow.

Although the linkage system between element arrays varied from zone to zone, only one type of ceramic insulator was used throughout the whole installation.

All the support links were of Incoloy D.S. wire, which at 800°C. has a tensile strength of 10·5 tons/sq. in. The stress in the most heavily loaded link at this elevated temperature was less than 0·1 ton/sq. in., allowing a high mechanical factor of safety. This wire has a melting point of not less than 1,320°C. and a coefficient of expansion of $18{\cdot}5 \times 10^{-6}$/°C.

Thermocouples

Temperatures were measured at some 400 points by means of chromel-alumel thermocouples. All the internal and external positions for the permanent thermocouples were used and in addition a number of temporary points were selected.

Particular attention was paid to the positioning of thermocouples on the pressure-vessel support skirt, gas-duct stubs and sphere. It was possible to record the temperature distribution down the support skirt in various planes around its periphery. This enabled a check to be made on the performance of the thermal pocket at the top of the skirt.

The temperature along each gas-duct stub was measured at several points to ensure that no large temperature gradients occurred. In addition, four pairs of thermocouples were connected differentially to record any temperature variation between selected points at the top and bottom of the large irregular-sectioned forgings at the duct roots.

A pair of thermocouples, one connected to the top crown and the other connected to the bottom crown, were arranged to indicate the temperature difference between the two points, thus enabling the controller to regulate the heat input to maintain an even temperature distribution throughout the pressure vessel.

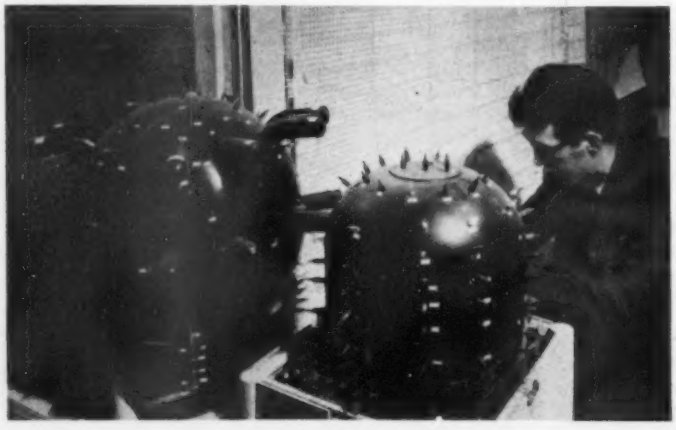
The vessel could be symmetrically divided into four quadrants and, as it was fairly reasonable to assume that the heating pattern would be similar in each quadrant, it was decided to connect strip-chart recorders to the thermocouples in one quadrant only, with a few check thermocouples in the other quadrants.

In addition to the thermocouples used for the pressure vessel and its contents, about 20 were placed in the surface of the concrete biological shield at the equator level, on the concrete beams forming the soffit, and in the concrete supporting the reactor skirt, to ensure that the rise in concrete temperature was not excessive.

Thermocouples were also used to measure the temperature of the heater strips at various points.

Instrumentation

To eliminate the continuous logging of large numbers of temperatures by an operator, two special instrumentation and recording systems were employed. Approximately three-quarters of the



1 *Two models used to determine the position of* 100 *selected thermocouples during the stress-relieving of the pressure vessel. The peg board can be seen in the background.* [*Courtesy: G.E.C. Ltd., England*

thermocouples were connected to a digital typewriter recording system which presented the temperatures in the form of a printed list, while the remainder were connected to six strip-chart recorders. The strip-chart recorders were thus available to control the heating cycle for a limited period in the event of failure of the digital typewriter system, as well as providing a record which could be interpreted more readily than that of the digital typewriter. The readings from the strip-chart recorders were plotted in the form of a graph on a peg board in the control room.

Adjacent to this board were two models, one of the pressure vessel and the other of the inner heat shield resting on the grid (fig. 1). Fixed to the models were small lamps in positions corresponding to those of the 100 thermocouples represented on the peg board. By placing a plug in a thermocouple position on the board the appropriate lamp on the model lit up. This arrangement enabled the position of a thermocouple in the vessel to be located quickly if it showed the temperature in that part to differ too widely from the mean temperature of the whole structure.

Forming part of the peg board were two other display systems. The first showed the power loading of each heater circuit in the pressure vessel and the tapping position of each of the 24 auto-transformers; the second showed the cycling of the tubular duct heaters. The complete peg board and models were designed and constructed by the South of Scotland Electricity Board Industrial Advisory Service.

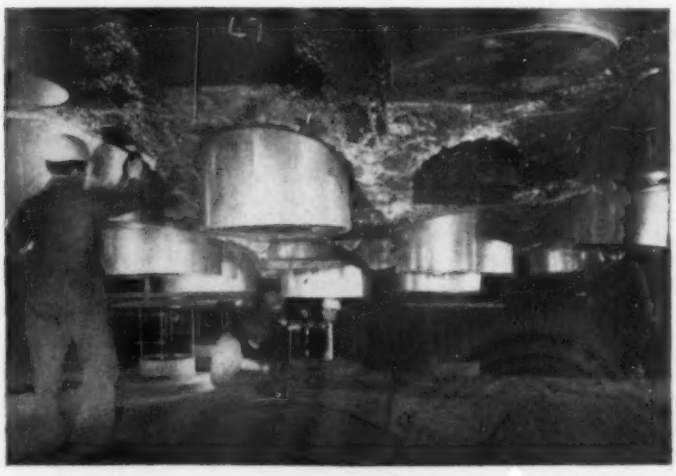
The equipment for the digital display system was specially developed by G.E.C. and was arranged for either automatic or manual operation. On automatic operation all the thermocouple readings were sequentially scanned and printed out by an electric typewriter. Four uniselectors each handled one-quarter of the 300 thermocouple circuits. The output side of each uniselector was connected to an Electroflo-type 198 potentiometric indicator scaled to read 1,000°C. Each indicator was also fitted with a Hilger & Watts digitizer having an output in the Watts reflected decimal code. When the four indicators were balanced the output of each digitizer was decoded in turn by a single decoding unit and passed to the I.B.M. electric typewriter.

Once during a complete scan (*i.e.* through all four uniselectors) each indicator was connected to a standard reference corresponding to a reading of 800°C. Accuracy of the potentiometric indicators was 0·25% f.s.d. and the accuracy of translation was ±1 digit. The system was calibrated at 550°C. and a correction card was made to cover other temperatures.

Since the electric typewriter was able to print 10 digits/sec., multi-bank uniselectors capable of switching the inputs of the four indicators simultaneously were employed, the four outputs being printed out sequentially. The print rate was thus 2½ digits/sec. Additionally the five differential thermocouple readings were registered on a separate chart recorder so that special and continuous observation was possible.

Cabling and power supplies

Because of the high temperature involved, special arrangements were adopted to take the power supplies to the heating elements and from the thermocouple points inside the pressure vessel. Stainless steel conductor rods were used for the power con-



2 *Rocksil thermal insulation applied to the bottom crown of the first reactor pressure vessel at Hunterston, Scotland. The charge nozzles were insulated individually and then covered by a thin aluminium container as shown. This formed part of the preparation for stress-relieving the 70-ft. dia. pressure vessel.*
[*Courtesy: G.E.C. Ltd., England*

nection to the heaters. Welded connections were used between the heater strips and the stainless steel rods to obviate faults at these points during stress-relieving.

Mineral-insulated stainless-steel-clad cables were used for all thermocouple leads. At suitable points outside the pressure vessel these cables were terminated in junction boxes from which normal multicore cables were run to the control room.

Although the South of Scotland Electricity Board made a 4·5-MW. supply available for the stress-relieving, in practice the maximum demand never exceeded 3·6 MW., corresponding to 2 kW./ton of metal treated.

Thermal insulation

All external surfaces of the pressure vessel, ducts and nozzles were insulated to reduce heat losses. In most cases this insulation consisted of two 3-in. thick layers of Rocksil, but in some instances, namely, round the duct stubs and skirt, the thickness was increased to 12 in. Aluminium foil was widely used to reduce radiation and so protect the concrete surfaces (fig. 2). As a further precaution against undesirable increases in the temperature of the concrete, arrangements were made to pass about 300,000 lb. of air per hour through the biological shield cooling system.

Stress-relieving operation

As there was no previous experience to draw on for controlling the heating rate of vessels of this size and complexity, it was not possible to lay down a set of rules governing the operation. Initially the bottom crown heaters were switched on at their lowest setting, *i.e.* half load, and held at this level until the heating pattern emerged. The switching instructions were then based on this pattern. It was agreed to limit the rate of temperature rise to less than 5°C./h. and on this basis it took approximately seven days for the pressure vessel to reach the stress-relieving temperature of 550°C., at which it was soaked for 12 h. Throughout the whole operation there was not a single heater failure. As would be expected, the overall rate of heating was controlled by that of the bottom crown, because natural convection tended to take the heat away from this part of the sphere. After the soaking period the vessel was left to cool for nine days before removing the thermal insulation. Entry to the vessel was delayed a further two days.

Conclusions

Over the past few weeks a considerable number of tests have been carried out on the fabricated structure to check the success of the stress-relieving. These tests were laid down by Lloyd's Register of Shipping (Land Division), with the approval of the UKAEA, the South of Scotland Electricity Board and the consultants to the Board, Kennedy & Donkin. They included crack-detection tests on 10% of all nozzle welds on the inner heat shield and on the grid and 100% crack-detection tests of the nozzle welds in the shell and on the gussets. Ultrasonic examination of selected areas on the top and bottom crowns was also carried out.

The absence of any faults in the pressure vessel or its contents indicated that the stress-relieving was entirely successful. Certain minor modifications to the layout of the heating system should result in a reduction in the time taken to treat the second reactor pressure vessel. The use of radiant-heating strips, freely suspended inside the vessel, has been fully justified by the result.

Precipitation in low-carbon steel under cyclic loading

concluded from page 376

about by precipitation hardening in the slip bands. During additional heating at temperatures of 97 and 128°C. to the main extent the undeformed matrix took part in the increase in hardness; the sequence of the hardness curves and the morphological appearance of the structure correspond to the conditions of combined hardening.

The different character of the breakdown of the supersaturated solid solution of alpha iron through precipitation during static and cyclic loading points to the specific properties of the structure of the permanent slip bands, which form during the alternating deformation of the grains of ferrite, and are the centre of the breakdown in cohesion through fatigue.

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Elevated bell-type furnaces for cable works

PIRELLI-GENERAL CABLE WORKS LTD. has placed with the General Electric Co. Ltd. an order for a bell-type furnace installation for the bright annealing of copper under vacuum conditions. The charge is to be in the form of wire and strip coils or wire on spools, and the rated output will be over 250 tons per week.

The installation will comprise four identical bell-type furnaces designed for a maximum temperature of 500°C. Contrary to normal procedure each furnace will be supported in a fixed elevated position, and the charge, carried on the furnace base, will be lifted up into the furnace. The furnaces, which will be about 7 ft. dia. and 8 ft. high, will each be rated at 114 kW. and will be provided with three individually-controlled heating zones.

A full complement of bases and hoods will be provided. Each base will consist of a heavy frame fitted with flanged wheels to allow it to run on floor rails, with a vacuum-tight corrugated top cover. This corrugated envelope fits on top of the heavy frame and is sealed to it by means of a water-cooled rubber ring. The space within the envelope can be evacuated through a vacuum connection fitted with a shut-off valve. Each base can carry a load of 2½ tons distributed over three shelves. These are supported one above the other in the charge space which has a diameter of 39½ in. and is 65 in. high. A thermocouple projects from underneath the base into the charge to enable its temperature to be recorded.

The four furnaces are to be arranged in a line, with a cross-traverse trolley running in a pit in front of and parallel to them thus enabling a base with its charge to be run off the cross-traverse trolley on to rails mounted on the top of a ram situated below the furnace. Beyond this cross-traverse trolley pit is to be a rail system for carrying the furnace bases to the furnaces. This system will consist of four pairs of parallel rails, laid at right angles to the line of furnaces. Three sets of these rails will be fitted with hydraulically-operated puller mechanisms used for handling the furnace bases, and the fourth will contain the vacuum connection for roughing down the bases. Another cross-traverse trolley is to be provided at the end of this floor rail system opposite to the furnaces, and one of its functions will be to assist in unloading and loading the charge of a furnace.

Cycle of operations

The complete cycle of operations for a particular charge will be as follows. A charge will be prepared in the loading section and placed on the furnace base, a hydraulic ram assisting in this operation. The base is then rolled directly on to the cross-traverse trolley running on rails in the floor pit, the trolley then being taken by the rail system to the vacuum connection point for roughing down the envelope.

After the envelope has been evacuated the base is transferred to the other cross-traverse trolley which takes it to the appropriate furnace, where a hydraulic ram raises it into the furnace. At this point the base is connected to another vacuum system designed to hold the container at a high degree of vacuum during the annealing operation. When this annealing operation has been completed the base is removed and taken to one of the sets of rails fitted with a puller mechanism, where it is allowed to cool down. Provision is to be made for flooding the containers with a gas to accelerate the rate of cooling of the charge.

Six furnace bases can be accommodated at a time on each set of rails, so that by a judicious selection of furnaces, a continuous programme, employing the furnaces to a maximum, can be operated.

The vacuum systems will consist of a water-ring-type pump for roughing down the base and two rotary mechanical pumps for holding the containers under vacuum in the furnace at an absolute pressure of less than 500μ. These two pumps are to be so arranged to serve all four furnaces. Bourdon-type gauges will be used to indicate the pressures in the system.

The provision of the ram at the loading position and the puller mechanism on the cooling lines will keep operator fatigue to a minimum, the operator only being required to load and unload the bases and to move single bases to and from the cooling lines and return line.

This furnace is designed and manufactured jointly by G.E.C. and Vacuum Industrial Applications Ltd.

Stedall Machine Tool Co. has been appointed by Impregnated Diamond Products Ltd. distributors of the Sparcatron range of spark erosion machines used in the manufacture of press tools, forge dies, etc., and Sparcard tungsten carbide impregnating machines for cutters, lathe tools, etc.

BOOKS

X-ray metallography

By A. Taylor. John Wiley & Sons, Inc., New York and London, 1961. Pp. 993. £10 16*s*. net.

THIS COMPLETELY NEW book is much larger than the author's previous 'Introduction to X-ray Metallography,' and this fact reflects the growth of the subject over 15 years. The aims are similar—it is intended to be a book that can be studied without prior knowledge, to be used as a reference and guide to the literature and the author hopes it will be of service to students and research workers in universities or in industry.

The book deals first with the scope of the subject as conceived by the author and then goes on to cover the production of X-rays. It is possible that a chapter (7) on Crystallographic X-ray Tubes should have followed here. The third chapter (50 pages), however, deals with radiography, microradiography and X-ray microscopy. The author possibly had a problem here. Should this chapter have been included here or at the end of the book? It is complete enough to be instructive but does not give quite the same service to the laboratory as many of the later chapters dedicated to crystallography and related subjects. These provide the main justification for the title. The principles of symmetry, diffraction, and X-ray intensities are dealt with interestingly and adequately. The metallurgical reader who is none too sure about the reasons for certain relationships will benefit from the derivations given here. The author also describes the experimental methods for obtaining diffraction patterns in this first part of the book. This material—itself the substance of a separate volume—completes the foundations of experimental work and theory leading to interpretation in terms of structure. The remaining *two-thirds* of the book take the reader through all the varied contributions of X-ray diffraction to the study of metals and other metallurgically interesting materials. In addition practical information is provided about contingent subjects such as thermal equilibrium diagrams. It is just a reflection of the scope of the subject that orientation textures take up a chapter of 90 pages and internal stresses another of 100 pages. Dislocations are involved in the former chapter and then appear from time to time in the interpretation of various metallurgical phenomena. The book concludes with two chapters—on chemical analysis by X-ray procedures and on the applications to refractories oxides and corrosion products. These could have been much longer! Finally, there are some very useful appendices and tables.

The author has every reason to be satisfied that he has achieved his stated objectives. Furthermore, like its fore-runner, only much more so, it will meet a continuing need in giving metallurgists a practical view of the diverse contribution that X-rays can make to their subject. It will perhaps encourage more of them to use the powerful methods available. If any reader feels that something has been missed out or insufficiently covered and something else given too much prominence this will only be because the author had set himself an almost but not quite impossible task! There are many more than 1,001 things in its 1,001 pages, more than that number of references and 419 excellent illustrations. The price, therefore, is commensurate with its size and will certainly not inhibit the purchase of the book for libraries or laboratories. Individuals will still find more here in one book than in two or three others (which may or may not exist) and will count themselves to have gained much.

K. W. ANDREWS

Cemented Carbides

By P. Schwarzkopf and R. Kieffer in collaboration with W. Leszynski and F. Benesovsky. Macmillan Co,. New York, 1960. Pp. 349, illustrated. £5 5*s*. net.

IN VIEW of the eminence of Schwarzkopf and Kieffer in the field of hard metals and cemented materials, it should be stated that this new book in no way duplicates an earlier English volume published by the authors in 1953. This earlier publication, 'Refractory Hard Metals,' dealt with binder-free or uncemented borides, carbides, nitrides and silicides. The present book, on the other hand, is primarily concerned with refractory carbides bonded together by comparatively soft and ductile metals. Taken together, these books now represent a complete English version of the German-language volume 'Hartstoffe und Hartmetalle,' published by the authors in 1953, though it is obvious that the present book contains a great deal of revision of the earlier German text to take into account the noteworthy progress in the technology of cemented carbides during the intervening seven years.

The authors have attempted to cover every aspect of the subject and have largely succeeded in producing a text which should become a standard reference source for many years. While the authors' interest is primarily focused on carbides, and particularly tungsten carbide, as the cutting, wear-resisting or heat-resisting material, they have also included a chapter on oxide (ceramic) and boride cutting materials.

The book opens with a historical survey of the development of cemented carbides from the early years of the present century up to the present time. The technology of the cemented carbide industry is then discussed, albeit somewhat briefly, before a consideration of the general metallurgical principles of the sintering operation. The metallurgical reader might feel disappointed with the rather elementary treatment given to the mechanism of sintering but, as in all the chapters, a most comprehensive bibliography is provided for reference purposes. The reactions during liquid phase sintering (Chapter V) receive better treatment, although an inquiring reader will again need to refer to the references—in this instance 74 references for 24 pages of text—for a full appreciation of the ternary system W—Co—C.

The middle third of the book contains a succession of chapters dealing with testing methods, and the mechanical, physical and chemical properties of various carbide compositions.

The final two chapters divide the applications of the various carbide compositions under either wear-resistant materials or metal cutting tools. The special interests of the engineer concerned with machining metals with cemented carbide tools are also catered for here.

The value of this book undoubtedly lies in the wide coverage given to the subject. There appears to be something for everyone while the comprehensive, if not distressing, list of over 1,000 references should provide material for the most inquisitive reader. The contents could have been improved, however, by enlarging the chapters on 'Technology of Cemented Carbides' and 'The Mechanism of Sintering' and it is considered that this could have been achieved at no increase in publication costs by radically pruning the contents of the final two chapters devoted to the uses of cemented carbides in industry. The apparently never ending parade of photographs depicting dies, rotary drilling tools, percussion drills, etc., contributes nothing to a scientific textbook.

H. L.

NEWS

Nitrogen shrinking

EIGHT STEEL TRUNNION PINS, each over 2 ft. across, were nitrogen shrunk to fit four 100-ton ladles recently at the Teesdale Ironworks of Head Wrightson & Co. Ltd. To fit the ladle bores, the diameters of the pins were shrunk by an average of 0·04 in.

A light, insulated tank 2 ft. deep was made to hold the liquid nitrogen supplied by British Oxygen. The tank could be moved on rails above the ladles which were set up on bogies. By means of a 2-ton electric hoist each pin was lined up with the ladle bore and then raised while the liquid nitrogen tank was positioned underneath. The pin was lowered into the tank and immersed in liquid nitrogen pumped direct from a B.O.C. road tanker. On average each pin was immersed for about 52 min. A total of 1,232 gallons of liquid nitrogen was used.

Nitrogen shrinking was the most economical and only practical way of fitting the trunnions. Heating the ladle bore would have been much more difficult and costly and taken a great deal longer. In addition, the metal might have been distorted and weakened.

Following two successful test shrinkings, supervised by technicians from British Oxygen, the Wolverhampton firm of Bayliss, Jones & Bayliss Ltd. plans to make increasing use of the technique in assembling components for heavy machine tools.

One of the test-pieces was a gear-wheel pinion for a 300-ton billet shear. The pinion's spigot, with a diameter of 7·999 in., was contracted to fit the wheel bore of 7·993 in. The shrinking operation took only 30 min. and used 56 gallons of liquid nitrogen (equivalent to 8,000 cu. ft. of gas). The nitrogen was supplied direct from a B.O.C. road tanker.

Normally the gear-wheel would be heated in a coke fire for 7–8 hours to expand the bore sufficiently for the spigot to be inserted. This method sometimes results in distortion, scaling and softening of the tempered steel gear. All these risks are virtually eliminated by the nitrogen shrinking technique, which is 50% cheaper.

Low-cost furnace atmospheres from blast-furnace gas

At the recent Sheffield Industrial Exhibition the Gas Atmospheres Division of the Incandescent Heat Co. Ltd. announced a new process for the low-cost production of nitrogen/hydrogen mixtures from blast-furnace gas. Hy-Nitrogen (sometimes termed HNX), consisting of nitrogen with 1–7% hydrogen, is finding increasing use in the heat treatment of steel strip and sheet. The gas provides an inert atmosphere for bright annealing, and does not form soot during cooling, since it contains no CO. Hydrogen is present in sufficient quantities to combine with any oxygen leaking into the furnace and also to prevent water vapour from causing blueing.

Non-destructive testing

The Non-Destructive Testing Society of Great Britain is holding a conference at Chester from September 21 to 23. The theme of the conference is 'Industrial radiology today,' and it is intended to base the papers and discussion on the application of newly developed aspects of industrial radiology. The papers will include such subjects as low kV. radiography, xeroradiography, linear accelerators, betatrons, large gamma ray sources for radiography, and current safety regulations.

The conference is open to all who are interested, whether they are members of the Society or not. A conference fee will be charged, which will include the cost of morning and afternoon refreshments. This will be 15*s*. for members and 30*s*. for non-members.

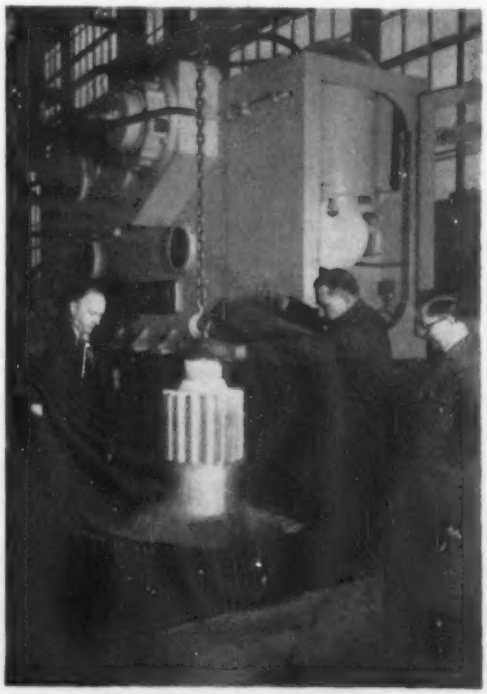
Effluent and water treatment

The second Effluent and Water Treatment Exhibition and Convention at the Seymour Hall, London, from October 31 until November 3, will be nearly twice the size of the one held in 1960. There will be a number of developments and innovations on show at the Exhibition and at the Convention papers will be presented covering the subject internationally.

Increasingly severe restrictions are being imposed by River Authorities on the type of effluent discharged. The growing volume of water required for industry cannot always be provided economically from available sources and recovery of used water is of prime importance.

Registration is £4 per delegate and forms are obtainable from the organizers: Thunderbird Enterprises Ltd., 140 Cromwell Road, London, S.W.7.

Gear-wheel pinion for a 300-ton billet shear being lowered into position after shrinking with nitrogen



PEOPLE

THE INSTITUTION of Production Engineers announces that **Mr. Harold Burke,** M.I.MECH.E., M.I.PROD.E., has been elected to the presidency for 1961-62.

Mr. Burke, who became a member over 30 years ago, has worked wholeheartedly for the Institution ever since. A Birmingham man, Mr. Burke is a prominent and popular figure in the Midlands, where he enjoys a well-deserved reputation for the successful exercise of industrial administration at all levels.

Educated at Birmingham College of Technology, Mr. Burke studied economics, industrial organization and industrial law at the University of Birmingham. He served his apprenticeship with Vickers Ltd. and, after holding appointments in several engineering firms, in 1947 he joined Elfson Ltd. as managing director. When the Engineering Division of this company was purchased by Concentric Manufacturing Co. Ltd., he accepted the appointment of director and general manager. He is now deputy chairman and joint managing director of Concentric Ltd., chairman and managing director of Concentric (Engineering) Ltd., chairman of Fletcher Bros. (Pressings) Ltd., and a director of Concentric's other subsidiary companies.

Mr. Thomas Murray has been appointed industrial safety officer for the Bradley & Foster group of seven companies in Staveley Industries Ltd. He is based at the head office of the group at Darlaston, Staffordshire.

Mr. R. G. Huxtable, M.B.E., is the new secretary of the Gas Council. He succeeds **Mr. Wilfrid Bailey,** who becomes deputy chairman of the Southern Gas Board.

Mr. Huxtable has been secretary of the South Eastern Gas Board since 1956, and was previously the board's solicitor.

Hilger & Watts Ltd. announces that **Mr. A. H. Campbell,** M.A., M.I.E.E., who has been a director of the company since 1951 and general manager since 1954, has been appointed joint managing director with **Mr. G. A. Whipple,** M.A., M.I.E.E., F.INST.P.

Mr. Campbell was a scholar at Winchester College and Rex Moir Prizeman at Cambridge University. After practical experience in the industry with the Cambridge Instrument Co., he saw service in the last war with the Royal Corps of Signals, finally as lieutenant-colonel commanding 8 Corps Signals.

For several years Mr. Campbell was chairman of the North London District Advisory Committee for Industry, and since 1960 he has been chairman of Council, Management Research Groups.

The Lead Development Association announces that **Mr. P. C. Fryer,** B.A. CANTAB., has been appointed to the staff. Mr. Fryer is a metallurgist and prior to joining the LDA was on the staff of the Morgan Crucible Company. He will be principally engaged in development work for the lead industry in the battery field.

The United Steel Companies Ltd. announces that **Mr. Stafford Beer,** who has been head of the company's department of operational research and cybernetics since its inception in 1957, has resigned to become managing director of a new international firm of operational research consultants based in London. **Mr. David Owen,** previously assistant head of the department, succeeds Mr. Beer.

Mr. R. M. Higginbottom, B.SC., has joined Graphoidal Developments Ltd. as a physical chemist. Previously he was employed as research assistant with the Permanent Magnet Association, Central Research Laboratory.

Mr. David Parkinson has joined the Public Relations Division of the Basil Butler Co. Ltd., advertising agency, from the public relations department of Handley Page Ltd.

Educated at Harrow Grammar School and the Northampton College of Advanced Technology, Mr. Parkinson is a qualified aeronautical engineer and metallurgist.

Following the appointment of Mr. H. B. Morris to the board of directors, Wickman Ltd. announces the appointment of **Mr. H. Andrews** as secretary and **Mr. H. L. Hudson** as chief accountant.

Mr. A. W. Jones, recently installed as president of the Scientific Instrument Manufacturers' Association of Great Britain Ltd., 20 Queen Anne Street, London, W.1, was born in 1914 and educated at University College School, Hampstead, London, at a day engineering course at the Northampton Engineering College, London, and a one-year student course at Standard Telephones & Cables Ltd.

In 1933 he joined Orr Radio, later Invicta Radio, as an inspector, becoming ultimately technical manager. On the company's absorption by the Pye Group he joined Pye Ltd. in 1938, working on research and development in radar during the war. In 1945 he founded Fleming Radio (Developments) Ltd., on a capital of £300 with accommodation in Clerkenwell. In 1953 he moved to Stevenage and the company now covers 38,000 sq. ft., employing 200 people, with a turnover of £350,000 per annum. In 1961 it will expand by another 20,000 sq. ft.

Mr. A. W. Jones was vice-president of SIMA for 1960-61 and has been a very active council member for the past four years.

OBITUARY

WITH deep regret the International Nickel Company (Mond) Ltd. announces the death of Mr. George Sandland who, at the height of his career, died suddenly when returning from a company sports outing at Birmingham last July.

Mr. Sandland, who will be remembered by many for his vigorous activities on his plating campaign, had been with the company for 35 years. Trained as an engineer-designer with Vickers-Armstrongs, he joined the late Sir William Griffiths and Miss E. W. Parker to form the triumvirate who transformed the Development and Research Department into a highly valued asset.

Latterly he has been prominent in the Nickel-plating Labelling Scheme, which is now reaching a state of maturity.

The death took place last July at Caterham, Surrey, of Mr. Burkewood Welbourn at the age of 85. Mr. Welbourn was a former director and chief engineer of the British Insulated Company. He retired in 1945 on the formation of BICC through the amalgamation of the B.I. Company and Callender's Cable and Construction Company.

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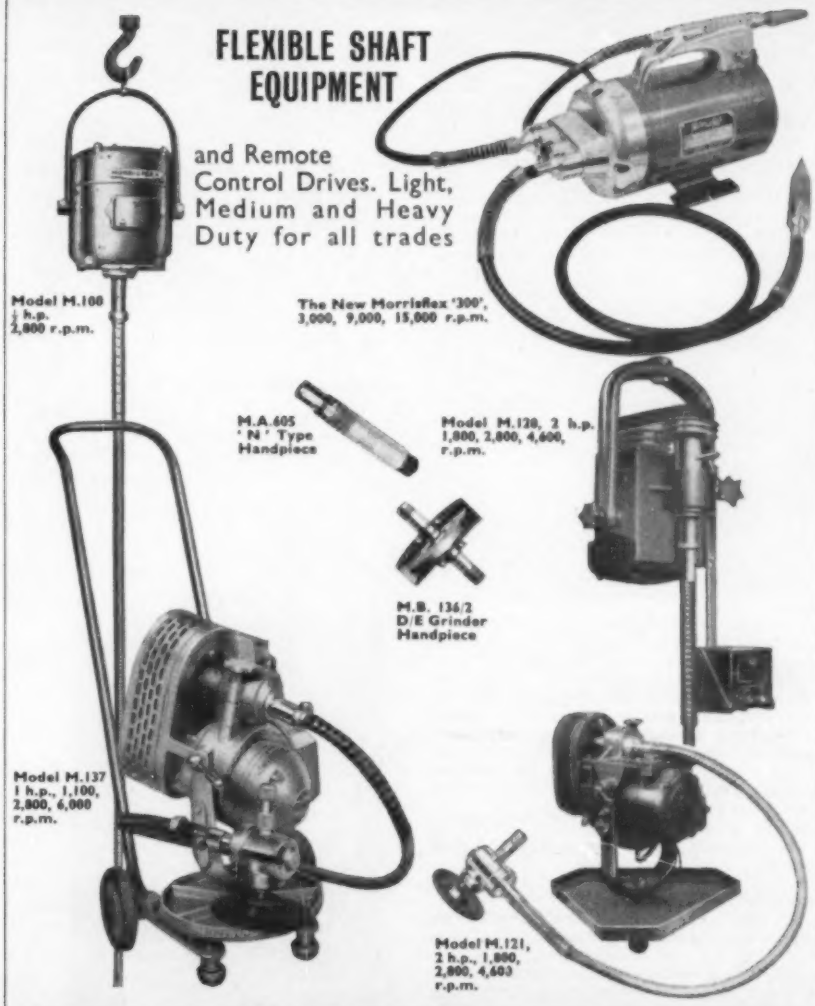

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INSTRUMENTATION

Portable oxygen analyser

Servomex Controls Ltd., who manufacture the Distillers Co.'s industrial oxygen analyser, have now developed a portable instrument utilizing the same magnetic susceptibility measuring cell (fig. 1).

The type DCL 101 portable analyser is a battery-operated device which can be regarded as an alternative to the Orsat apparatus for determination of oxygen anywhere in the range 0–100% to an accuracy of $\pm 0{\cdot}1\%$. Operation is simple and, as the device is linear, calibration at two points is sufficient to standardize over the whole scale. The zero is highly stable and a check of the span using air as a test gas is sufficient for most normal uses.

The analyser may be used with static samples or with a continuously flowing sample at rates up to 150 ml./min. The sample must be filtered and cooled sufficiently to remove condensate, but there are otherwise few restrictions. The measuring cell is particularly tolerant of variation of sample components other than oxygen and

1 *Portable oxygen analyser*

it is not in any way affected by thermal conductivity or density variations.

Experience with the industrial analyser has shown that the DCL measuring cell is very robust. It contains a very light dumb-bell-shaped test body suspended by a platinum ribbon in a non-uniform magnetic field. The torque on the test body produced by the presence of oxygen in the measuring cell is balanced by passing current through a coil wound on the dumb-bell. The balance condition is observed by means of a light spot reflected on to a scale and is obtained by adjusting a calibrated-source potentiometer. The read-out is taken direct from a linearly calibrated ten-turn dial.

Further details may be obtained from Servomex Controls Ltd., Chemical Instrument Division, Crowborough, Sussex.

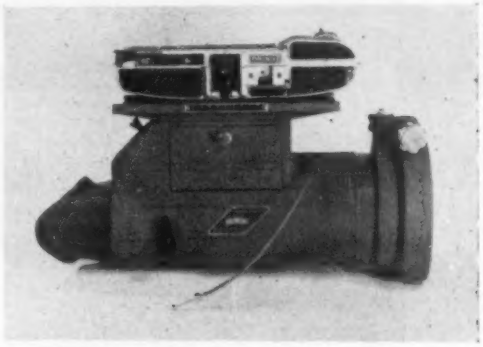
Versatile oscilloscope cameras

Aveley Electric Ltd. announce the introduction of two versatile cameras manufactured by Allen B. Du Mont Laboratories (fig. 2).

The type 299, with a variety of backs available for use with 120 roll or cut film, is for general-purpose recording from 5-in. oscilloscopes. It offers great versatility in obtaining single-frame recordings.

Type 302 incorporates polarid-land back for obtaining terminated 'print-a-minute' records on transparent or opaque film. This polaroid back can also be used on the type 299 camera.

The cameras incorporate a specially designed sliding back on the housing which permits the operator to adjust the cameras in relation to the lens and expose more than one trace on the frame. Detent stops position the camera backs for equally-spaced exposures,



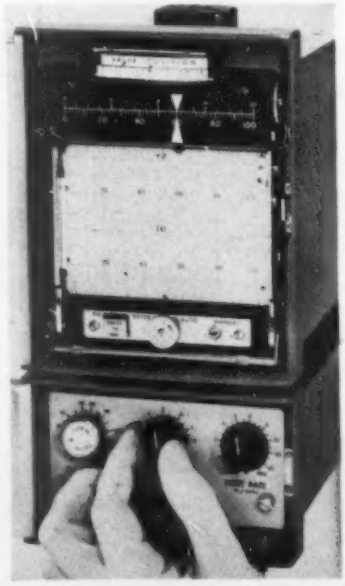
2 *Du Mont oscilloscope camera*

whilst the scale and pointer arrangement assists in positioning the back accurately for more than three exposures per frame. Simultaneous screwing facilities for data recording are also provided.

The choice of lens available is the Woollensac Du Mont 75-mm. F2·8 three-element lens, or a 75-mm. F1·9 six-element lens. Two bezel adaptors enable these cameras to be used with almost all 5-in. tube oscilloscopes.

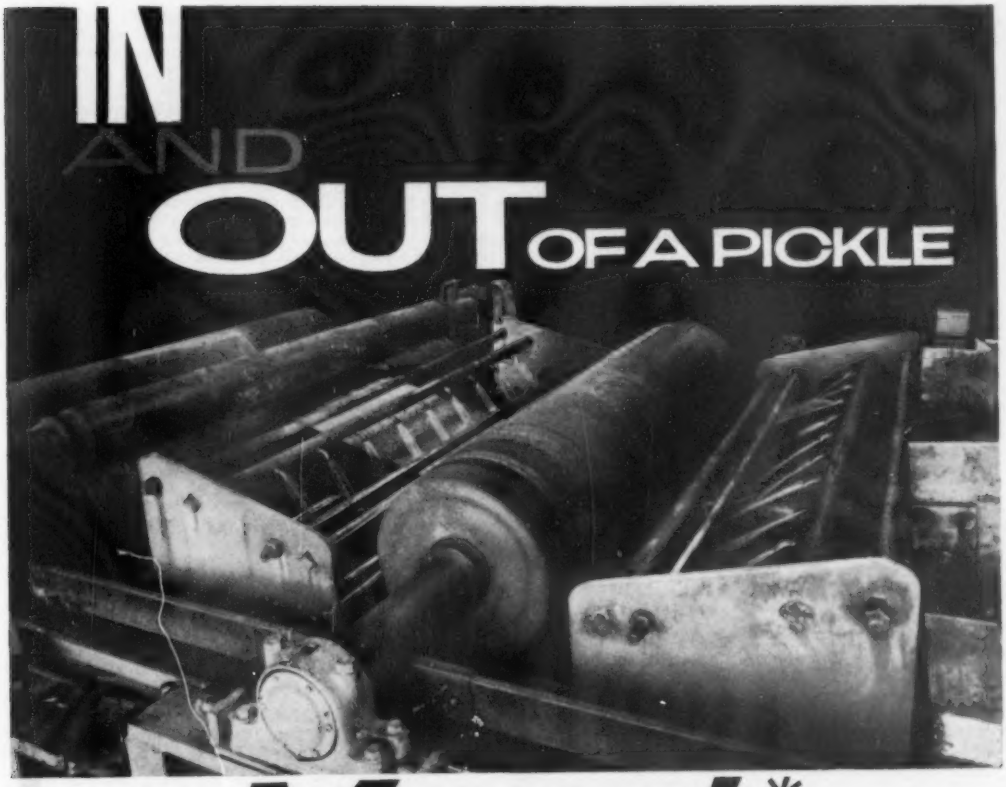
New electric measuring and control system

Marketing of a new electric measuring and control system



3 *A controller instrument with 'proportional plus reset plus rate action' mode, part of the ElectriK Tel-O-Set*

IN AND OUT OF A PICKLE



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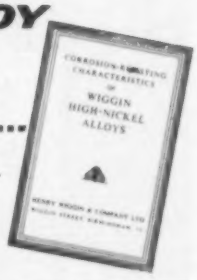

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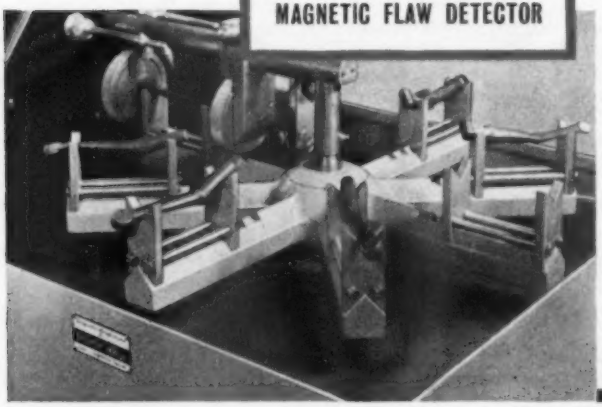

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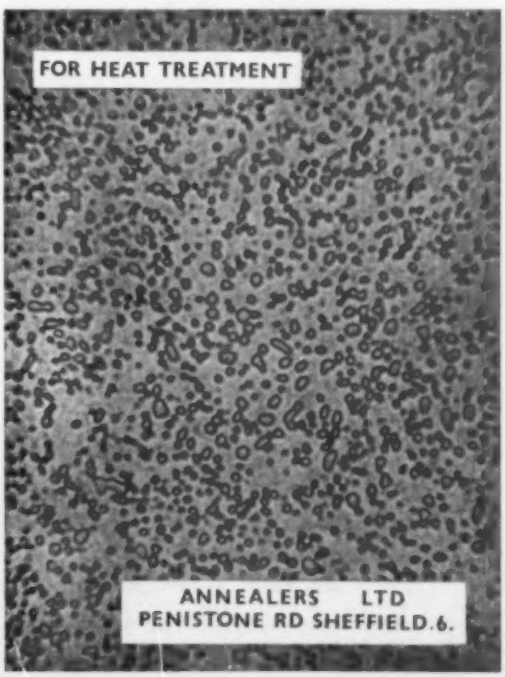

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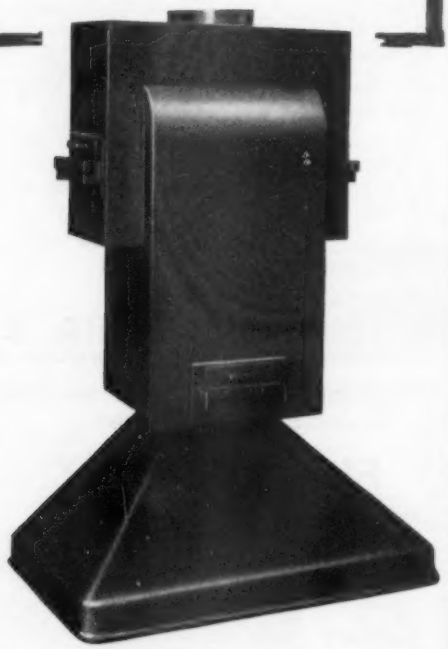

This photograph shows an Alldays & Onions UF/1 Dust Collector, primarily for use with hearths and designed to meet the requirements of the Clean Air Act.

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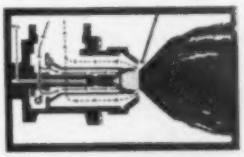

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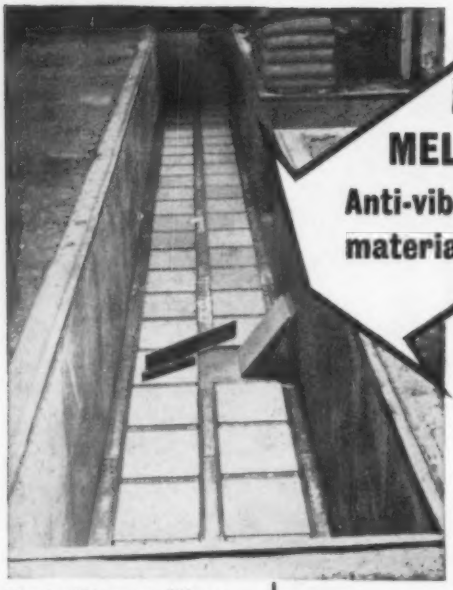

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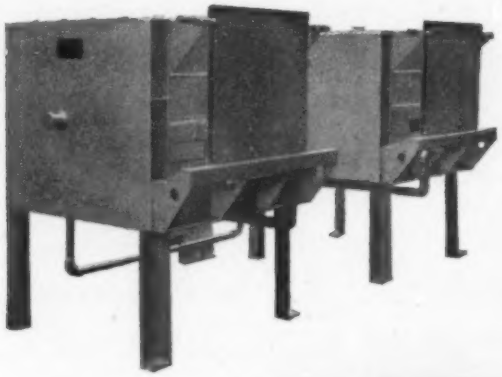

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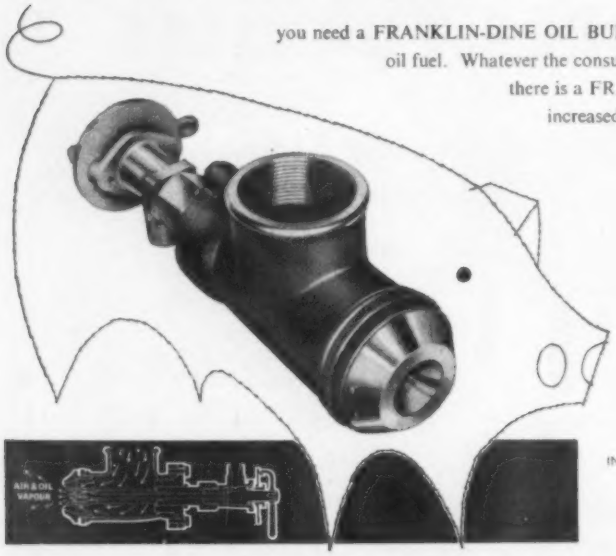

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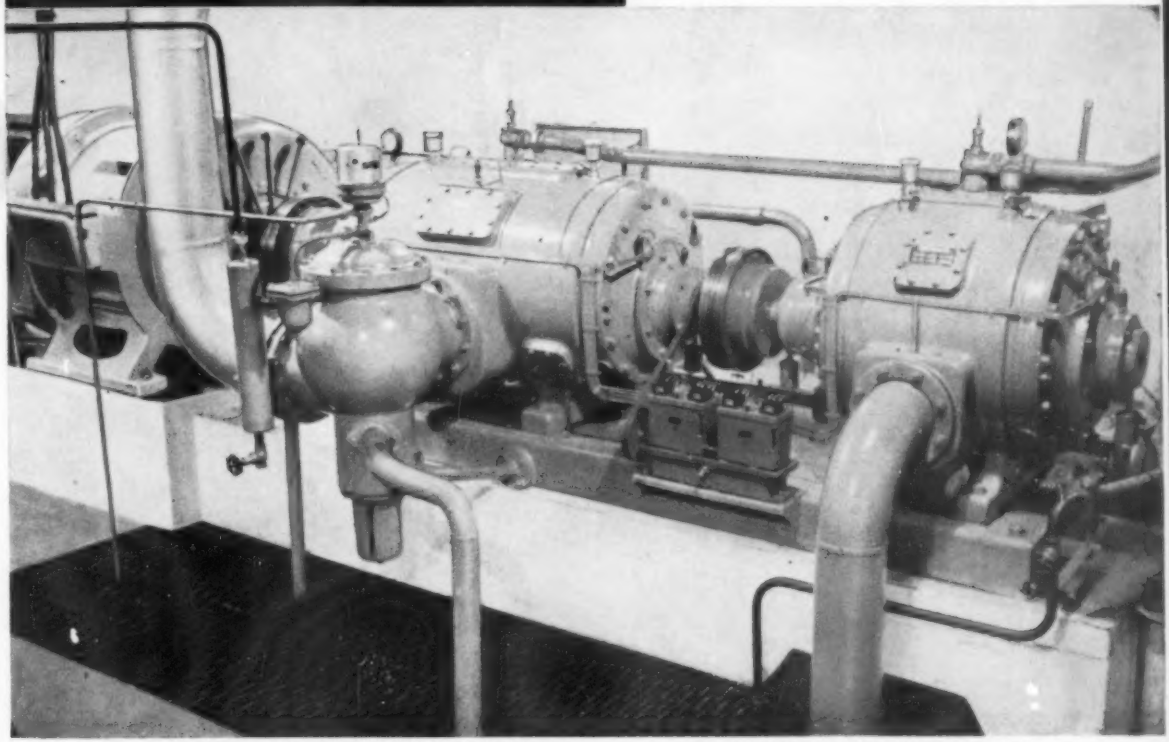

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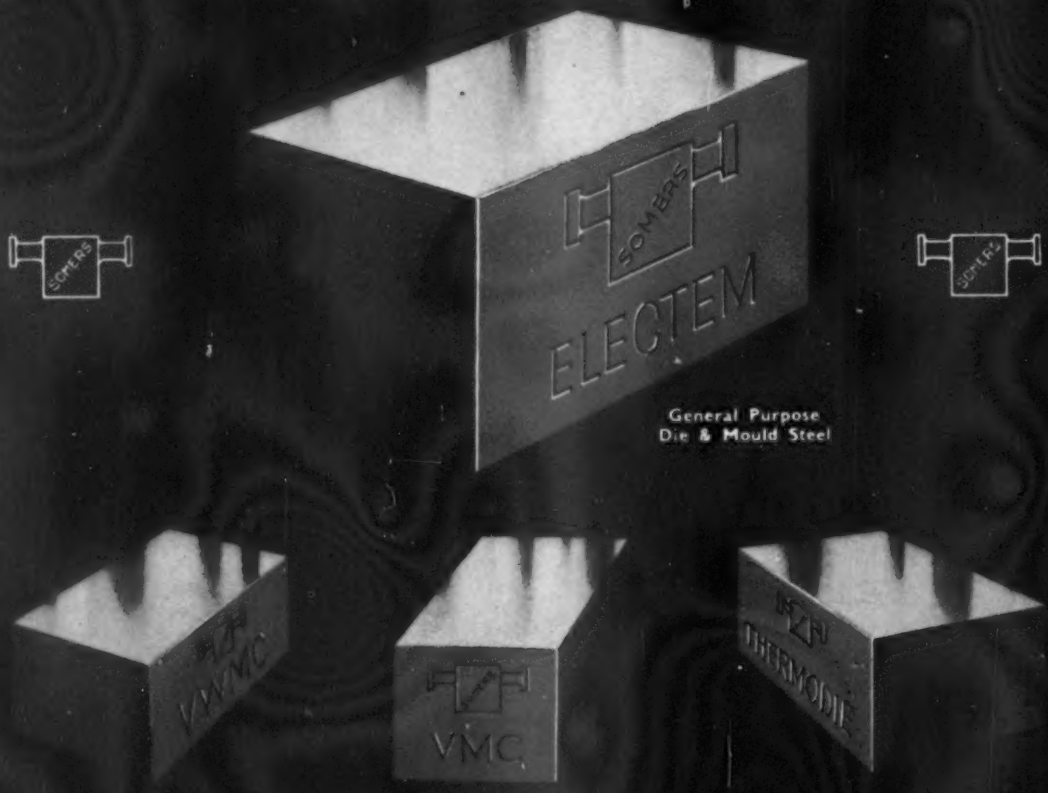

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